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ORIGINAL ARTICLES.

Dolerites Associated with the Karroo System, South Africa.—A Correction.

By Reginald A. Daly and Tom F. W. Barth.

IN an article with the foregoing title (Geol. Mag., Vol. LXVII, 1930, page 97) some unfortunate errors of statement, in part quite unaccountable, were printed.

On page 102 the first sentence should read: "The analyses of columns 1–3 inclusive fall in *auvergnose* of the Norm classification of analyses; the other two fall in *camptonose*."

On page 103, line 4 from the top, "col. one, Table IV" should read "col. 6, Table II."

On page 108 the paragraph beginning "In all cases . . ." was copied so as to be practically absurd. To make the meaning clearer this and the succeeding paragraph have been rewritten, to read as follows: "The matter may be looked at in another way. Again for the reason that early-formed olivine should be highly magnesian and correspondingly poor in iron, the settling-out of this mineral would give a distinctly higher ratio of (total) FeO to MgO in the derived rock than in the original plateau-basalt. Table A gives the ratios computed for the rocks in question:—

Table A.

	Ratio, total FeO : MgO
World plateau-basalt (Washington-Daly, 50 analyses)	2·05
World plateau-basalt (Tyrrell, 37 analyses)	1·73
Karroo dolerite (5 analyses)	1·53
Stormberg basalt (1 analysis)	1·46
World dolerite (20 analyses)	1·64
Tholeiite (8 analyses)	1·68
Whin Sill-dike (6 analyses)	2·21
Central Porphyritic rock, Mull (10 analyses)	2·50

"It is seen that the ratios for the average Karroo dolerite, the average world dolerite, the Stormberg basalt, and the average tholeiite are actually lower than either of the ratios for the averages of world plateau-basalt. The relation is reversed when the latter ratios are compared with those for the Whin Sill-dike average and the average for the Central Porphyritic type of Mull. Here, then, in two cases the hypothesis of differentiation by the settling-out of early olivine alone might seem to be supported; but against that conclusion is, as just noted, the failure of the Whin Sill-dike rocks or the Central Porphyritic rocks to show a decided excess of total FeO over that in plateau-basalt.

" Thus the results of both kinds of comparison in the much better studied British field agree to a considerable extent with the results for the South African instance. Such a situation can hardly be accidental and merits attention in speculations regarding the early stage in the differentiation of basaltic liquid."

The Structural Connection between the Coast Range of British Columbia and the Cascade Range of Washington.

By C. H. Crickmay, University of California at Los Angeles.

(With Folding Map.)

Connections between Mountain Systems.

It has been made eminently clear by Suess[1] in his great synthesis of the structure and form of the planet that between those mountain systems which come into contact with one another there are very different types of structural connection. Suess' interpretations of various examples, now famous, are so well known that no repetition is here necessary, Moreover, his brilliant work has invested the subject with a surpassing interest which has led many others to give it their attention. Already the structures of the junctions between many of the world's mountain systems are understood. But the connection between two of the great mountain systems of western North America, the Coast Range of British Columbia and the Cascade Range of Washington, has been largely neglected by geologists, or misinterpreted, if not indeed completely misunderstood. Even Suess' interpretation is open to objections: it fails to separate the two ranges, and to correlate the structures of the Cascades in any way with those of the Interior Plateaux or the Rocky Mountain System.

Purpose of this Paper.

This paper has been written, therefore, with a view to bringing together some of the more important observations bearing on this problem, and in an attempt to clarify the matter. Many of the facts presented herewith have, of course, been culled from the literature, but many have been gathered in the field by the writer, who has since 1919 visited most of the significant localities in north-western Washington and south-western British Columbia, comprising an area of about 10,000 square miles. The work has been done as circumstances allowed—most of it in numerous short expeditions made by the writer from the city of his birth and home, Vancouver. However, in 1924 and 1926 full field seasons were spent in the Harrison Lake district at the expense of the Geological Survey of Canada, and in 1929 the writer worked for the best part of the summer at his own expense in the Skagit Range. The original purpose of the author's work was the elucidation of Mesozoic stratigraphy and palaeontology and in that sense the work is not yet complete. But enough has been gathered to make possible this exposition of the broader structural relations.

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[1] *Das Antlitz der Erde*, 1883–1909.

SOURCES.

The writer has already supplied the Geological Survey with the manuscript of a detailed report on the Harrison Lake area, an abstract of which has been published.[1] And he hopes to publish in the near future a detailed report on the geology of the north-western Skagit Ranges, from the massive sedimentary pile of Mount Cheam to the mighty volcanic cone of Mount Baker.

Following is a list of the more important published works from which the author has obtained significant data :—

H. Bauerman : " Report on the Geology of the Country near the Forty-ninth Parallel of North Latitude West of the Rocky Mountains," *Report of Progress*, 1882–4, Geological Survey of Canada, 1885.

G. O. Smith and F. C. Calkins : " A Geological Reconnaissance across the Cascade Range near the Forty-ninth Parallel," *Bull.* 235, U.S. Geological Survey, 1904.

C. H. Clapp : " Southern Vancouver Island," *Memoir* 13, Geological Survey of Canada, 1912.

R. A. Daly : " Geology of the North American Cordillera at the Forty-ninth Parallel," *Memoir* 38, Geological Survey of Canada, 1912.

C. H. Clapp : " Geology of the Nanaimo Map Area," *Memoir* 51, Geological Survey of Canada, 1913.

R. G. McConnell : " Texada Island, B.C.," *Memoir* 58, Geological Survey of Canada, 1914.

N. L. Bowen : " A Geological Reconnaissance of the Fraser River Valley from Lytton to Vancouver, British Columbia," *Summary Report for* 1912, Geological Survey of Canada, 1914.

R. W. Brock : " Structure of the Pacific Region of Canada," 2nd Pan-Pacific Science Congress, 1923.

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[1] *Abstracts of Dissertations*, Stanford University, 1924–6, vol. i, 1927.

C. H. Crickmay: "The Stratigraphy of Parson Bay, British Columbia," University of California Publications, *Geology*, vol. xviii, 1928.

Many other works deal with the region treated in this article but it is hardly possible or needful to list them.

GEOGRAPHY OF THE REGION.

The most north-westerly part of Washington and most south-westerly of British Columbia consists of a roughly triangular glacial plain of about 1,400 square miles area. This plain is bounded on the north by the squarish southern extremity of the Coast Range, on the south-east by the Cascade Range and foothills, and on the south-west by the waters of the Straits of Georgia. The region is drained by the Fraser River, which flows along the northern edge of the plain, and by smaller streams further south such as the Nooksak. These principal divisions of the area are shown in the small scale index map (Fig. 1).

GENERAL GEOLOGY.

The Coast Range, as is well known, consists largely of Upper Jurassic granodiorite containing here and there masses of altered sedimentary rocks which include Carboniferous, Triassic and Jurassic. A notable feature of these ancient sediments, apparently not well known, is the small extent to which they are deformed. For instance, on Harbledown Island the Trias and Jura dip gently toward the batholith which has invaded them. Throughout the length and breadth of the Straits of Georgia the older sedimentaries present mostly gentle dips. Moreover, the individual formations have great areal extent as though involved only in shallow folds. In the Mount Garibaldi district and along the eastern shore of Howe Sound (save for the exceptional Britannia area) the sedimentary rocks are nearly horizontal. All of this seems to show that among the effects accompanying the intrusion of the late Jurassic batholiths deformation of the country rocks was one of the least.[1] The Harrison Lake area shows some good confirmatory evidence. There the Neocomian marine deposits, bearing pebbles derived from the eroded batholith, rest with very slight discordance, indeed in some places perfect accordance, upon the Jurassic strata within 3 miles of the main batholith. We may, therefore, draw the conclusion that the intrusion of the immense late Jurassic batholiths was neither preceded nor accompanied by any diastrophic "revolution". And the corollary follows that any high-angled structures found in the region must be traced to a later orogeny or to a special cause.

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[1] There is, of course, no proof that any of the observed deformation resulted from the process of intrusion.

To the east of the Coast Range and in contact with it is a considerable range of mountains of a very different character. Dawson, Daly, and others have, following Dawson's principles of delimiting and naming mountain ranges, included these with the Coast Range. The writer, following the Suessian principles, sees in this a mistake. The Coast Range proper is a re-elevated Jurasside system. The

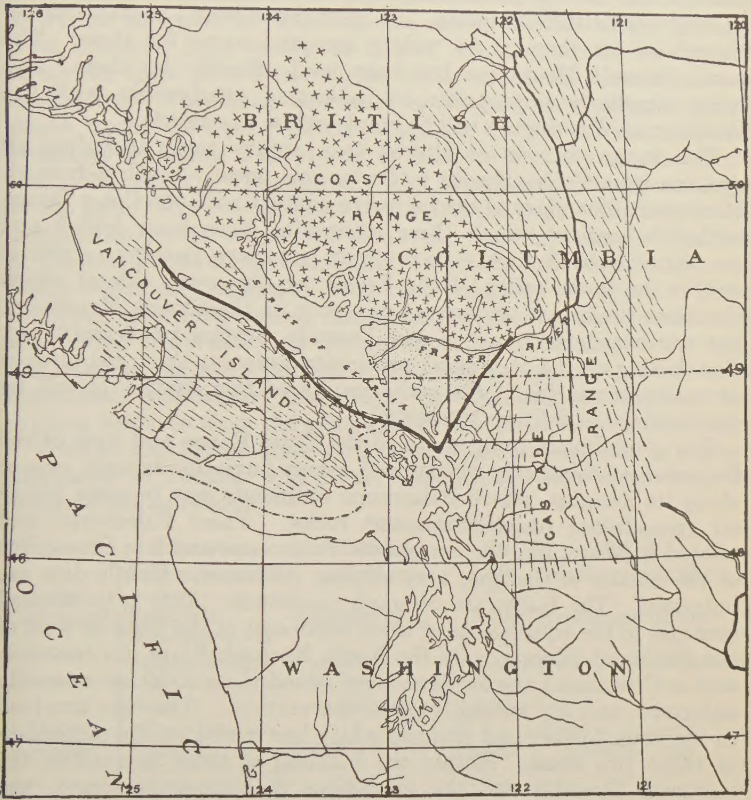

FIG. 1.—Index map of north-western Washington and south-western British Columbia. The international boundary is shown as a line of dots and dashes. The Coast Range, including plutonics and areas of dominant Jurasside structures, is shown as an area of small black crosses. The distribution and trends of dominant Laramide structures are shown by dashes. East of the Coast Range these coincide with the Cascade Range; west of the Coast Range, with the Vancouver Island Mountains. The glacial plain which lies upon the "protected salient" is shown by stippling. The heavy black line marks the southern boundary of the salient, around the southern apex of which the Laramide folds form a syntaxis. The small rectangle is the area represented in the areal geology map.

mountains to the east of it are a re-elevated Laramide range. Their structures connect them with the Interior Plateaux of British Columbia. Their history correlates them with the distant Rocky Mountains. At the present day they form an independent geologic province in British Columbia. They ought to bear a separate name, though so far there is no widely accepted name for them. The name Cascade Mountains has been used officially for them,[1] and being singularly appropriate in indicating relationship with the Cascades of Washington will be employed in this article.

This range consists of altered sedimentary rocks including all systems from Carboniferous to Cretaceous, mostly much deformed. Its western boundary is the intrusive contact with the Coast Range batholith, against which these mountains have been folded and overthrust from the east. Its southern boundary, purely an artificial one, is the lower cañon of the Fraser, on the south side of which the same rocks and structures reappear in the Skagit Mountains, the northernmost range of the Cascade System of Washington. The finding of the structural continuity between these two groups of mountains is one of the main results of this study. It will be discussed more fully in the sequel.

The glacial plain lying south of the Coast Range and west of the Cascades contains only glacial and recent fluviatile deposits except along its margins, where Palaeocene sediments rest in some places on granodiorite or other ancient rocks. These Palaeocene and related beds are, like the correlative Palaeocene and late Cretaceous of the Straits of Georgia, very slightly deformed. Gentle dips are universal. The faults are of small amplitude. This is in marked contrast to the equivalents of these rocks east of the plain or west of the Straits of Georgia. On the North Nooksak River, for instance, and at Cowichan Lake on Vancouver Island these rocks are intensely deformed, and dip at angles up to the vertical. They are involved in the main folding and faulting which has reared up the mountains of those two areas. Plainly the building of these mountains, the northern Cascades and the mountains of Vancouver Island, was post-Palaeocene. It is then the more remarkable that the Palaeocene and Upper Cretaceous of the glacial plain and Straits of Georgia are so slightly disturbed. It would seem as though these two areas together form a salient which has been protected more or less from the main violence of post-Jurassic deformation. The source of this protection is hard to know, though it seems probable that it is the result of peculiarities in the strength of the materials, and comes from some buried rigid mass, perhaps a southern extension deep beneath the surface of the Coast Range batholith. The latter, being relatively rigid as compared with the sedimentary rocks which surround it, would transmit tangential pressures perfectly without being itself deformed, and thus would brace the whole zone it occupied, protecting the weaker rocks lying in or on it.[1]

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[1] Map of New Westminster and Yale districts, Department of Lands, Province of British Columbia, 1914.

Structural Details of the Northern Cascades.—In order to trace the structural connection between the Coast Range and the Cascades it will be desirable to deal with the salient details of the geology from Harrison Lake to Mount Baker. Harrison Lake lies mainly along the trace of a great thrust fault, called the Harrison Lake Overthrust. This fault continues southward from Harrison and passes under the Fraser River at Agassiz, crosses the international boundary in Cultus Valley, and is finally cut off by another fault near Coal Creek, Washington. The Harrison fault dips steeply to the east. The overthrusting is toward the west. The maximum displacement is 10 miles. In places the fault is a simple break as at the south end of Harrison Lake ; in others it divides into several faults which are separated from each other by schuppen. These schuppen are readily seen on Long Island where there is a bewildering alternation of Jurassic and Cretaceous beds, all dipping to the east, and, except for the evidence of the fossils, appearing to form a continuous sedimentary succession. A diagrammatic cross-section is given below to show the relations of these intimately faulted beds.

West of this thrust fault, on the west side of the lake, is a great succession of Jurassic and Lower Cretaceous rocks which may be summarized as follows :—

	Formation.	*Lithology.*	*Thickness. feet.*	*Fossils.*
Lower Cretaceous	Brokenback Hill	agglomerates	3,600	*Aucella crassicollis.*
	Peninsula	sandstone	1,200	*Aucella canadiana.*
Upper Jurassic	Agassiz Prairie	argillite	5,000	*Anacardioceras perrini.*
	Kent	conglomerate	3,000	—
	Billhook	tuff	1,800	"*Cadoceras*" sp.
	Mysterious Creek	argillite	2,500	*Cadoceras schmidti* *Lilloettia lilloetensis.*
Middle Jurassic	Echo Island	tuff, ss., etc.	2,700	—
	Harrison Lake	agglomerates and lavas	9,200	*Cylindroteuthis themis.*
Triassic ?	Unnamed rocks at Camp Cove	various	3,000	—

Total thickness, 32,000 feet.

The basal contacts of the Harrison Lake, Kent, and Peninsula formations, are gently unconformable. The discordances are the results of Triasside, Divesian, and Jurasside crustal disturbances.

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[1] R. W. Brock, *Structure of the Pacific Region of Canada*, 1923.

The other contacts are conformable. These formations are strongly folded against the Coast Range batholith, the eastern margin of which lies about 7 miles west of the lake.

East of the fault and lying on the east side of the lake is a thick succession of Palaeozoic and Mesozoic rocks which may be summarized as follows :—

		feet.
Jurassic	Schists and argillites, with obscure Upper Jurassic ammonites	4,000
	Greenstones and schists of pyroclastic origin	8,000
Triassic	Slollicum series—schists, argillites and greenstones	10,000
Carboniferous	Chilliwack Series—argillites with great limestone lenses yielding *Productus* sp., etc.	3,000
	Total thickness	25,000

These rocks have all been greatly compressed and deformed so that their study is a matter of great difficulty. They have been thrust upward and westward by virtue of the Harrison Lake Overthrust.

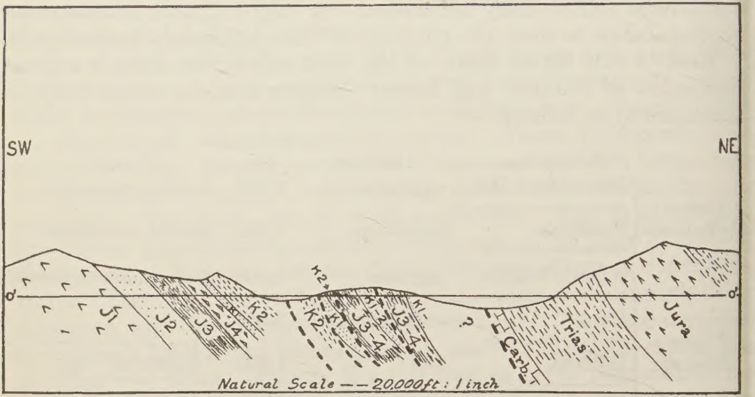
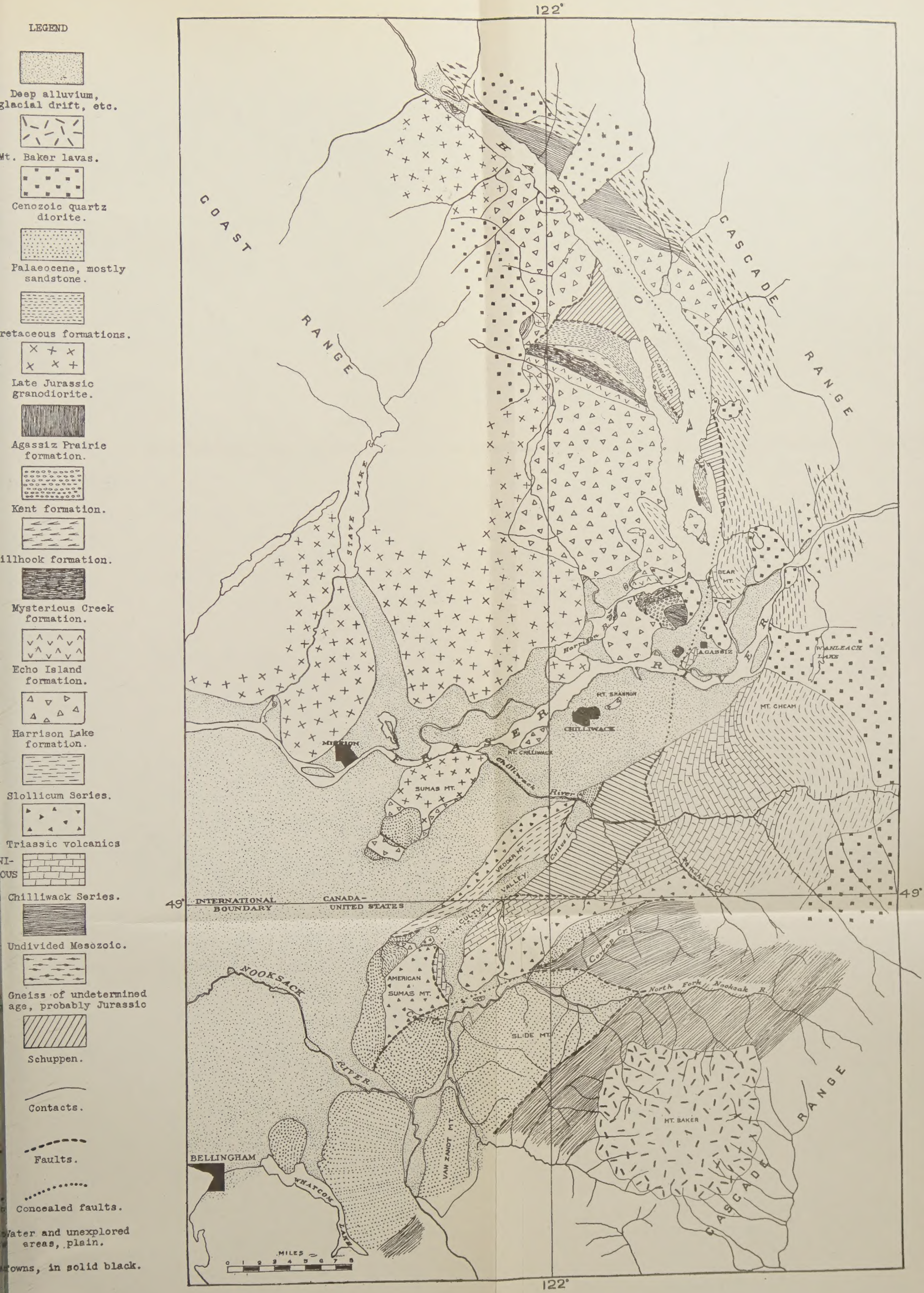


Fig. 2.—Cross-section of Harrison Lake at Long Island. O′–O′ line denotes sea- and lake-level. J1 denotes Harrison Lake formation. J2 denotes Echo Island formation. J3 denotes Mysterious Creek formation. J4 denotes Billhook formation. K1 denotes Peninsula formation. K2 denotes Brokenback Hill formation. Heavy, dashed lines denote faults. Light lines denote other contacts.

Both groups of rocks have been invaded by small bodies of quartz-diorite of middle Cenozoic age. This rock is fresh and unaltered, and in that respect notably different from the old, chloritized plutonics of the Coast Range. One such body, almost large enough to be called a batholith, lies across Harrison River valley just below the efflux of the lake, and extends to the south-east passing north of Agassiz, crossing the Fraser at Cheam View, and continuing into the mountains beyond Wahleach Lake. This igneous rock cuts



Geological Map of the Coast and Cascade Ranges.

[*To face p.* 488.

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fairly across the great thrust fault and all the associated high-angled structures. Hence the diorite is plainly younger than the fault, and yet withal the Fraser River has incised its valley many thousands of feet into the diorite.

The sedimentary formations run south across the Fraser and then swing to the south-west, following with rough parallelism the boundary of the Coast Range batholith. The Chilliwack Series which makes up most of Bear Mountain north of Agassiz reappears with its great limestone lenses in considerable prominence on the western slopes of Mount Cheam. Then it swings to the south-west making a broad band, 3 or 4 miles wide, where it crosses Chilliwack River, but narrowing somewhat beyond. Finally it disappears beneath the Slollicum rocks near Kendall, Washington, as a result of the decreasing magnitude of displacement of the main overthrust.

The Slollicum Series which makes up the east side of Bear Mountain crosses the Fraser and forms the rugged peaks of Mount Cheam. It continues as an irregular band across Chilliwack Valley and is finally cut off in the North Nooksak Valley by a cross fault which has displaced the Palaeocene sandstones and shales down against the older rocks. This fault, which may be called the North Nooksak fault, is a nearly vertical thrust. The steepness is a remarkable characteristic, shared, however, by most of the other faults younger than the Harrison Lake Overthrust.

In the upper part of Chilliwack Valley the Slollicum Series is cut off by the mid-Cenozoic quartz-diorite. But to the south of this, between Tamihy Creek and Mount Baker, the Triassic is succeeded by Jurassic and Cretaceous formations, and faulted-in selvages of Palaeocene rocks. The geology of this area has not yet been thoroughly explored.

Of the formations which lie west of the thrust fault on Harrison Lake, only the massive Middle Jurassic volcanics make much of an appearance south of Fraser River. These occur in Shannon, Chilliwack, and Sumas Mountains, separated by the alluvial plain under which the Jurassic sedimentary formations presumably lie buried.

On Sumas Mountain the middle Jurassic porphyries, mistakenly mapped as Chilliwack Series by Daly, are cut by the late Jurassic granodiorites. Upon these two lie unconformably the Palaeocene sandstone, shale, and conglomerate, named the Huntingdon formation by Daly. This formation has in general a low dip to the west; but near the south end of the mountain it is cut through by a very steep, east-west, thrust fault of about 1,500 feet displacement, which brings the Jurassic porphyries to the surface. This locality lies on the eastern border of the " protected salient ", referred to above. The low dip of the Palaeocene shows the connection with the latter. The faulting is an echo from the orogenic upheaval a short distance to the east.

Vedder Mountain is largely a complex of igneous rocks, mostly

Triassic extrusives corresponding to the upper part of the Slollicum Series. Its eastern slope is of Triassic sediments. Just east of the north end of this mountain a small selvage of Palaeocene conglomerate and sandstone is wedged in next to the main thrust fault. The fault here is divided by schuppen made up of alternating Carboniferous and Lower Cretaceous rocks which Daly, regarding them as one continuous sedimentary succession, called the Cultus Series. Between the south-west end of Vedder Mountain, and American Sumas Mountain, lies another selvage of Palaeocene rocks, also intimately involved in the thrust faulting. These occurrences, hitherto overlooked by geologists, are immensely important because they show that the main compression which brought about the mountain-building is of post-Palaeocene date. But the date can hardly be much later than early Cenozoic: a succession of very considerable geologic events, and so, presumably, a long period of time has passed since. In simplest terms—since the final completion of the orogenic compression, the region has been invaded by quartz-diorite stocks and batholiths, and these in turn have not only been denuded, but have been deeply dissected by erosion. The Fraser Valley has been cut through them. Incidentally this means that this part of the Fraser Valley is of comparatively recent origin.

The structure of the American Sumas Mountain is very complicated. It can be indicated only in a general way. The central mass of the mountain is of greenstone and serpentine, including intrusives as well as extrusives. The north-eastern part of the mountain is of the thrust Chilliwack Series. The ancient sediments and greenstones of the west slope of the mountain are overlapped unconformably by the Palaeocene, which dips steeply to the west under the alluvium of the glacial plain. The changes which have produced the striking differences in preservation between the Mesozoic rocks below this unconformity and the Cenozoic above may be attributable in part to the Jurasside orogeny, but are probably in the main the result of the mid-Cretaceous orogeny.

The southern half of American Sumas Mountain is composed entirely of Palaeocene and related rocks which are separated from the older rocks north of them by the North Nooksak fault. This continues up the North Nooksak Valley for some distance eastward. To the west it is overlapped by recent and glacial alluvium. It forms the north boundary of a broad belt of folded and faulted Cenozoic sediments which form Slide Mountain, Van Zandt Mountain, etc. These have yielded excellent collections of fossil plants, especially on Cowap Creek. They are all of early Cenozoic age. This belt of Cenozoic rocks may be followed to the south-west to Bellingham, where its folds show a syntaxial relation with those of the Vancouver Island Cretaceous and Palaeocene. This belt is hemmed in on the south-east by older formations similarly deformed. Mount Baker, a great basaltic cone, undeformed though much eroded, rests upon this basement of older rocks.

CONCLUSIONS.

It has been seen from the discussion and from examination of the maps that formations and structures are continuous from the Cascade Mountains of Washington to the "Cascades" of British Columbia. In other words these two groups of mountains though separated by the Fraser Valley are structurally one. They were formed as a continuous chain early in the Cenozoic. The structural trends are roughly parallel with the boundaries of the Jurasside Coast Range batholith and its probable southern continuation, the "protected salient". This makes it seem as though the Cascade Mountains, were formed as a result of the compression of the geosynclinal cumulus of sediments against the resistant mass of the Coast Range batholith. The syntaxis between the folds of the Cascades and those of the Vancouver Island Mountains is very important. Unluckily it is ill-exposed. Through it one may discern that the structures of these two ranges bear the same relation toward the Coast Range: they are thrust toward it as against a vertex.

The valley which the Fraser has cut through the Cascade Range and across its structures is merely an erosional gap: it marks no tectonic line. Its origin is much later than that of the mountains it traverses. The manner of its formation is obscure. The old hypothesis that the present course of the Fraser dates from late Cretaceous time is quite untenable in the light of newest findings. Further the mapping of Eocene sediments as coterminous with the present boundaries of the Fraser Valley, as in *Guidebook No.* 8 of the Geological Survey, is manifestly wrong. The present valley was formed long after the Eocene sediments had been caught up in the greatest orogeny of which western British Columbia shows a record—the Laramide mountain-making.

Notes on the Petrology of the Bufumbira Volcanic Rocks of Uganda.

By W. C. SIMMONS, B.Sc., A.R.C.Sc., F.G.S.

IN view of the probability that there is likely to be some little delay in publishing the official Memoir on the Bufumbira volcanic rocks, which is in course of preparation by Mr. A. D. Combe and the writer, with, we hope, collaboration with authorities in England, permission has been given to publish a short summary of the results so far obtained in the investigation of these rocks. Mr. Combe has made a careful geological survey of the ground and has separated on his map forty-nine flows from nearly forty different centres situated at the south-west corner of the Uganda Protectorate. The remainder of this large volcanic field lies in the Belgian Congo to the west and south, and though all of those volcanoes, several of which are still active, have been visited by geologists and specimens of the rocks obtained, no very detailed field-work has been published on them, either by us or any other observers up to the present time [1]; so far as is known to the writer.

We have already given summaries of the work done on our area in 1925, 1926, 1927, and 1928 in the Annual Reports of the Geological Survey of Uganda for those years, and as it seems now clear that the publication of the Memoir on the work must wait till the Memoir on, and geological maps of, parts of the Ankole and Kigezi tin-bearing areas have been seen through the press, this brief summary of progress to date is thought to be desirable in view of the fact that little is known of this area of very interesting leucite-bearing rocks, and particularly as we have here, probably, the largest mass of such unsaturated basic rocks in the world. The area of the volcanic flows can be judged from the small sketch map (Fig. 1), which is approximately correct as to details. The western edge of the map roughly corresponds with the margin of the lavas and, though it shows the positions of the main volcanoes, it is only accurate for that part in the north-east corner which lies in the Uganda Protectorate, and with which we are more especially concerned. The distance from Muhavura to Nyamlagira is about 33 miles and the width of the zone where craters occur is about 16 miles, while the total area occupied by the flows, many of which are leucite-bearing, amounts to something over 1,450 square miles. This includes the active volcanoes of Nyamlagira and Ninagongo, and the ancient and long since extinct and much weathered volcanoes of Sabinyo and Mikeno.

On the authority of L. Finckh (loc. cit.) it has been stated that there is a passage from the older trachyandesitic (*Monzonitischer*) to a newer leucite basanite facies (*Leucit-Theralitischer Magmaherd*). It is true that Sabinyo, which from its state of weathering is obviously one of the oldest of the volcanoes, largely consists of a rather basic enstatite andesite, and Finckh gives it on the authority of the geologist to the expedition, Kirchstein, that though most of the rocks of Mikeno, which is also another much weathered volcano, are leucitites, yet they overlie an older trachyandesite which can be sometimes seen in some of the deeper-cut gullies. On the whole the newer rocks of the field consist of basic leucite basanites, but at the same time it has been found that this gradation from intermediate to basic rocks cannot be followed in detail throughout, and the leucitites of Mikeno are themselves considerably older, judging from the amount of weathering of the mountain and the alteration of the leucite, than many flows of less basic composition from subsidiary volcanoes in Uganda. Mr. Combe gave in the *Annual Report of the*

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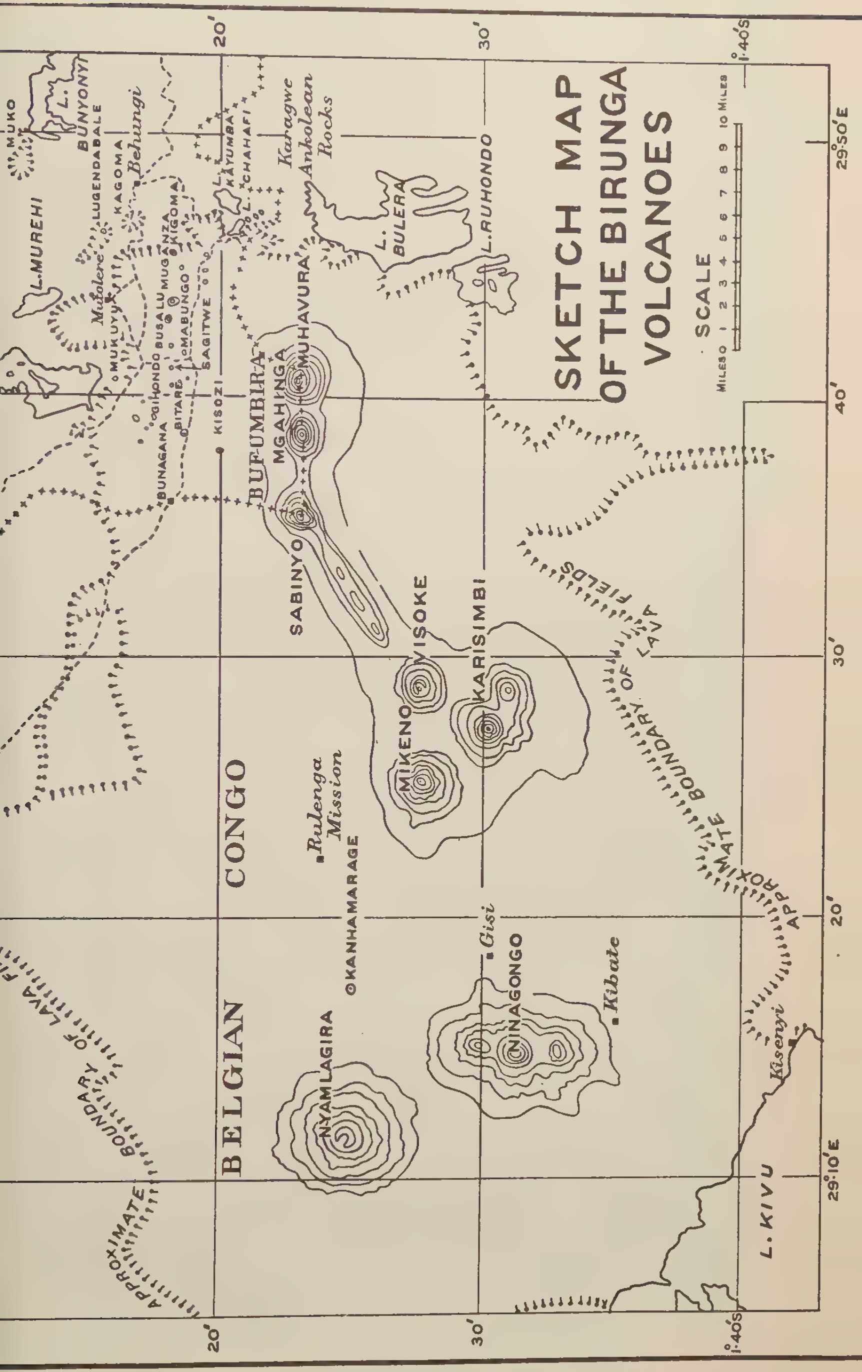
[1] Reference to published work can be made to: (1) Finckh, *Wiss. Ergebn. deutsch. Zentral-Afrika Exped.*, 1907–8 *des Herzogs A. F. zu Mecklenburg*, Band i, pp. 144, Leipzig, 1922. (2) Krenkel, *Geologie Afrikas*, vol. i, pp. 262–4. (3) Fritz Behrend, *Die Stratigraphie des Ostlichen Zentral-Afrikas*, pp. 140–2. (4) Hans Meyer, *Morphologie der Virungavulkane in Ruanda, Ostafrika*, Leipzig, 1927.


SKETCH MAP OF THE BIRUNGA VOLCANOES
SCALE
MILES 0 1 2 3 4 5 6 7 8 9 10 MILES
BELGIAN CONGO
BUFUMBIRA
L. MUREHI
MUKO
L. BUNYONYI
LUGENDABALE
KAGOMA
Behungi
Mulolere
MUKUYU
GIHONDO
BUSALU
MUGANZA
KIGOMA
MABUNGO
BITARE
SAGITWE
KISOZI
BUNAGANA
L. KAYUMBA
L. CHAHAFI
Karagwe Ankolean Rocks
L. BULERA
L. RUHONDO
MUHAVURA
MGAHINGA
SABINYO
VISOKE
KARISIMBI
MIKENO
Rulenga Mission
OKANHAMARAGE
Gisi
NINAGONGO
Kibate
NYAMLAGIRA
Kisenyi
L. KIVU
APPROXIMATE BOUNDARY OF LAVA FIELDS
APPROXIMATE BOUNDARY OF LAVA FI
20'
30'
40'
1°40'S
29°50'E
29°10'E

Geological Survey of Uganda for 1928 what were then his views as to the sequence of events in the extrusion of some of the lavas, and also gave a summary of what had been done to the end of that year. In Uganda there are in addition to the three main volcanoes, Muhavura, Mgahinga, and Sabinyo, thirty-four minor vents. In all forty-nine distinct lava flows were mapped by Mr. Combe, and microscope sections of numerous specimens from all the flows have now been cut and examined. At the end of 1929 Mr. Combe was able to make a geological traverse from Kisenyi on Lake Kivu across the interesting melilite nephelinite lavas north of that lake to the top of Nyamlagira and back through Bufumbira, and specimens of the rocks he collected have also been examined microscopically. The melilite leucite nephelinites are quite different from any rocks that occur in the Uganda part of the field, but the leucite basanites of Nyamlagira are very similar to those of Muhavura, and some coarsely crystalline rocks found in bombs, which have been ejected from Nyamlagira crater, are very interesting as probably representing the deeper seated magma and consist also of holocrystalline leucite basanite.

The rocks through which the flows have been extruded are predominantly argillaceous, shales, schists, and phyllites, with occasional quartzite beds, belonging to the Karagwe-Ankolean system, though it may be that the actual reservoirs from which the magmas were extruded lie down in the ancient rocks below the Karagwe-Ankolean. There are, as far as is known at the present time, no recognizable limestone beds among these rocks, and except for the somewhat calcareous breccias which occur to the north in Bunyoro, east of Lake Albert, and which lie near the local base of the Karagwe-Ankolean system there, and are microscopically and in all characters exactly similar to ancient glacial tillites, no calcareous beds are known in Uganda occurrences of these rocks. But it has now been suggested by Dr. N. L. Bowen, whom it was the writer's privilege to take out to Ankole to see one of the peculiar occurrences of diopside-tremolite rocks which Mr. Combe had discovered in the schists and in the intruding granites, that these highly calciferous rocks are probably the remnants of what were calcareous or dolomitic beds. These have been worked out by Dr. A. W. Groves in Uganda in the light of this suggestion and will necessarily be described in the forthcoming Memoir on the tin-bearing areas of Ankole, where they are important rocks of considerable scientific interest. Karagwe-Ankolean ancient sediments underlie the Bufumbira volcanic rocks and sometimes crop out in strike ridges through them, in what Mr. Combe has called Bufumbira "bay"[1] which may be described as an embayment, running east from the rift valley, and from which the volcanoes now protrude, and have been built up so that their summits far overtop the sides of the rift, which are here formed of the same ancient argillaceous rocks. It is therefore permissible to argue that there may have been some interaction between the few possible occurrences of calcareous rocks and the basic magma to produce leucitic types, but the quantity of leucite basanite is so vast and the amount of known calcium-bearing rocks so small that to call in the aid of this assimilation process seems to be to stretch the probabilities beyond the limits allowable. Unless it be supposed that the Archaean rocks below the Karagwe-Ankolean are highly calcareous, for which again there is no evidence where these rocks outcrop, it appears more probable that these lavas represent extrusions from one large reservoir of basic magma, or possibly from several reservoirs partially at times connected. If any conception of assimilation is to be upheld for the Birunga volcanic rocks, it had better be reserved for that part of the field where melilite nephelinites form conspicuous lava flows.

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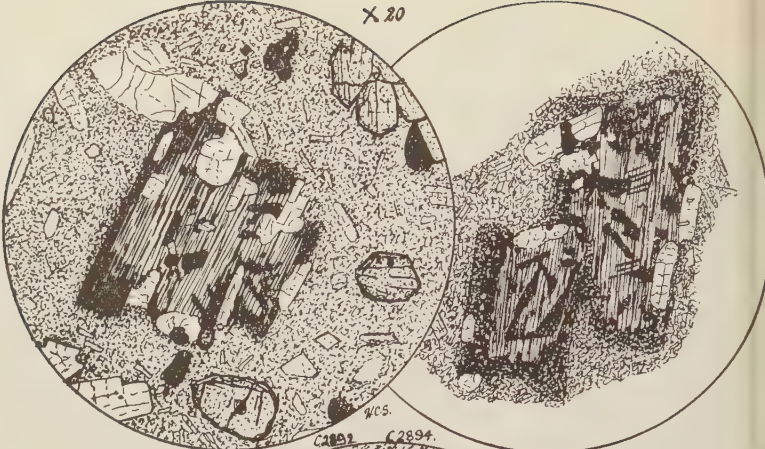
[1] *Annual Report of the Geological Survey of Uganda for* 1928, pp. 14–15.

The Uganda Volcanoes.

There is no need to do more here than to mention and very briefly describe some of the dominant or more interesting rock types, and to outline the results of the work as far as it has gone. The oldest of the Uganda volcanoes, Sabinyo, consists mostly of a pale grey to mauve coloured rock in which the most conspicuous crystals seen with the naked eye are scattered augite crystals (to 1 cm.) and smaller flakes of black mica. In microscope section the texture approximates to andesitic, with porphyritic larger augites and smaller pleochroic hypersthene crystals. Biotite occurs in scattered flakes which in section show reaction rims. Sections of biotite have been drawn (fig. 2) and these show inclusions in the mica of labradorite felspar and magnetite, and two stages of reaction are shown. It is also clear from the drawings that where, as is usually the case, the felspars are near the edge the mica has apparently been protected from the reacting magma and the rim is there absent. Magnetite occurs scattered throughout and the plagioclase felspar is chiefly labradorite. In some specimens derived from Sabinyo grains (to 5 mm.) of olivine are present, and they show signs of resorption. Mostly the lavas of Sabinyo were basic augite enstatite andesites, though among boulders probably derived from this volcano there are felspathic nepheline phonolites.

The lavas of Mgahinga are predominantly of leucite basanite and vary in texture from holocrystalline rocks to lavas with trachytic texture, while one remarkable isolated part of a flow has a dark glassy matrix in which are set large black augites (to 1 cm.) and olivines (to 5 mm.) and radiating groups and clumps of labradorite with a little scattered leucite. This rock might be near a porphyritic limburgite. Usually the Mgahinga lavas show porphyritic crystals of titaniferous augite and pale green olivine (both of the sizes mentioned above) with radiating groups of labradorite felspar; these larger phenocrysts occurring with leucite and magnetite in a groundmass composed of smaller crystals of all the above.

2



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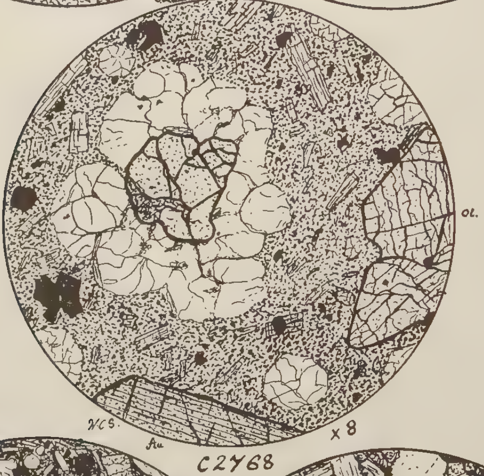

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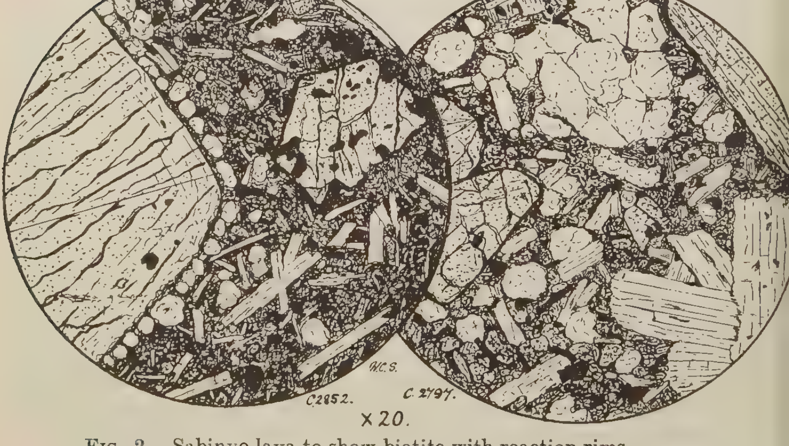

Fig. 2.—Sabinyo lava to show biotite with reaction rims.
Fig. 3.—Muhavura lava to show olivine surrounded by leucite.
Fig. 4.—Muhavura leucite basanite.

Muhavura lavas are also typically leucite basanites which vary in texture, like those of Mgahinga, from holocrystalline to trachytic and rarely glassy. The coarser grained types are the commonest, and in these flows the radial arrangement of the felspars so characteristic of Mgahinga lavas is not so noticeable. The augite and olivine crystals again are markedly porphyritic, and the quantity of leucite varies very much in different flows and different parts of the same flow; for instance on the east side of the mountain the lava is predominantly a rather fine-grained leucite basanite, with scattered augite crystals (up to 7 mm.) and olivine in less amount, and with not very much leucite in small grains, while in this flow there are patches very highly leucitic with many leucite icositetrahedra up to 1 centimetre in diameter (averaging 5 mm.) which make up together nearly half the volume of the rock. Other parts of the flows are very rich in augite which is well crystallized and reaches in size up to 2 centimetres. Olivine also occurs well scattered, but usually in less quantity than the pyroxene. Figures illustrating these rocks in section are given. In one flow with abundant leucite (C. 2768, fig. 3) from the east side of the mountain a section is shown of a typical leucite basanite (the magnification is only 8), and it is drawn to show leucite crystals round a core formed of an olivine grain. Another section is illustrated (fig. 4, C. 2852) to show small leucite crystals surrounding a large augite, and C. 2797 is drawn to attempt to show the typical characters of these beautiful leucite basanite rocks.

Subsidiary Volcanoes to the North.

North and north-east of the three main volcanoes in Uganda is a number of smaller craters which were active at different times, and in most cases it has been possible to designate the older of contiguous flows, but it would be difficult to draw up a list which would show the order of extrusion of all the lavas from the thirty-seven different centres, even allowing for the probability that some were contemporaneous, but Mr. Combe has been carefully over the field and the results of his observations will be published later in the map and Memoir.

On the sketch-map accompanying these notes the positions of some of the minor cones are indicated with the native names, and in nearly every case on the more detailed map the flows are named from the native name of the crater from which they came. The characters of some of the more distinctive flows shall be briefly described here. There is a number of lava streams from Mabungo which overlie those of Sagitwe and the Mabungo flows vary from rather fine-grained leucite basanites to felspar-free, leucite-rich rocks which are olivine leucitites or leucite basalts; and show variation in structure from trachytic to basaltic.

The Kisozi and Bitare flows occupy a considerable area and partly overlie lavas derived from Muhavura and Mgahinga and those from

Kisozi overlie the newer flows, at any rate, of Bitare. The rocks from both are rather fine-grained leucite basanites and have generally a trachytic texture. The Muko flow, which was responsible for the drowning of the valley and the formation of Lake Bunyonyi, is isolated from the main volcanic mass and lies out in the Karagwe-Ankolean rocks to the north-east. The rock is almost black and is crowded with pale green olivine crystals (up to 1 cm.) and fewer augites. In section the olivine crystals are colourless and idiomorphic and occupy nearly one quarter of the volume of the rock, and in much less amount is augite of pale colours varying from the largest sizes down to minute crystals, while with these ferro-magnesian minerals occur many small leucite icositetrahedra with often concentric or central inclusions in a fine-grained groundmass consisting of all these minerals with fine magnetite dust which, rather unusually for this field, does not appear in larger crystals. This rock is felspar-free and is an olivine-rich leucitite.

Mukuyu is also marked on the sketch map and the flows from this centre at the south end of Lake Mutanda mostly consist of dark-coloured rocks with pale augites (to 3 mm.), and olivine in the brown glassy groundmass which is crowded with minute leucite crystals. This rock is also free from felspar and probably will be found on analysis to be best called a limburgite.

These types may be taken as typical of the various minor flows and it is thus seen that these vary from leucite basanites, which though they are never coarsely holocrystalline like some of those of the main volcanoes, are fairly coarse grained in places, to olivine leucitites or leucite basalts, to lumburgites, and more acid types which have been called trachytic leucite basanites on account of their structure, which appears to be correlated with a more acid composition, though more analyses have yet to be made to prove this.

In several of these flows black biotite mica occurs, which in thin section is pleochroic from deep brown to pale reddish brown. This biotite often shows signs of partial resorption and appears usually to have been one of the first formed minerals. In the Kisozi flows flakes of biotite are seen standing up on end in the vesicles. So far as has been discovered up to the present, nepheline is absent from these rocks, and in this part of the field melilite also does not occur.

General Observations on the Petrology.

Generally speaking the coarsest grained rocks are found in the flows from the large volcanoes, but many of the lavas from the smaller as well as the larger cones are characterized by the presence of very numerous porphyritic crystals of augite and olivine. Leucite was in many of the coarser grained leucite basanites one of the first minerals to crystallize out, but generally in the leucite basanites, after the ferro-magnesian minerals, labradorite felspar has come out earlier and leucite then tends to be interstitial. In these felspar-bearing rocks the leucite has not generally so many inclusions as in the felspar-free leucitites and olivine leucitites. In the last two the icositetrahedra of leucite in the Uganda part of the field are generally minute in size and very commonly have inclusions, which either occur at the centre or are concentrically arranged in one or more zones. The inclusions are rarely radial as in the well-known rocks from Vesuvius. The usual sequence of crystallization of the commoner minerals is, magnetite and ilmenite, biotite, augite and olivine, labradorite and other plagioclase felspars, leucite, and finally a groundmass consisting of all the above minerals in smaller grains. In the rocks with a dark brown almost opaque glassy groundmass, which have been provisionally termed limburgites, there are usually phenocrysts of iron ores, augite, olivine, and leucite, which appear to have crystallized out in the order named.

It is hoped that these few notes will serve the purpose of directing interest towards this large field of leucite rocks, and it is believed that, when the petrology has been fully worked out and a series of analyses has been made, there will be more data for the formation of an opinion as to how leucitic rocks arise. In closing attention may be again drawn to the fact that on the eastern side of Uganda there is a large mass of augite-nepheline lavas, which are older than those of Birunga and were extruded near Mount Elgon from several centres, and these rocks also have local melilite-bearing lavas where they are, in this case, seen to be close to calcareous rocks.

On the Geological Evolution of the Chesil Bank.

By D. Baden-Powell, B.Sc., M.A., F.G.S.

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I. INTRODUCTION.

THE Quaternary System has always presented peculiar difficulties to those geologists who have attempted to work out its chronology, largely owing to the fact that it is not always easy to correlate the details of one locality with those of another. In some cases at least, this appears to be due to lack of knowledge of the detailed sequence of events within a limited district, whether such a sequence is considered from the climatic or from the cultural point of view, or from a combination of both. The main object of the present paper is to enquire into the state of our knowledge concerning the Quaternary and Recent train of events which have taken place within a limited district, so that in the future this area can be compared with others which will have been treated in a similar way.

The district chosen for the present investigation is that including and adjoining the Isle of Portland, in Dorset, and comprises the triangular piece of country whose corners are situated near Bridport, Weymouth, and the Bill of Portland. Within this district one of the most noticeable of the existing topographical forms is the Chesil Bank, the huge Recent storm-beach which stretches from Bridport to the Isle of Portland, and it has been found that a detailed study of the relation between this Recent deposit and various neighbouring Quaternary beds helps to clear up several points of dissension which have arisen in the past concerning the origin of the Chesil Bank.

Since these Quaternary deposits are almost entirely of a pebbly nature, it is the origin and history of the contained pebbles which are the particular concern of this paper; the more important of these deposits consist of river gravels, a raised beach on Portland and of the Head, and it is considered that the most logical way to look upon the Chesil Bank is as the latest stage in the local post-Tertiary sequence. Correlation with similar deposits outside the area will be avoided as much as possible, but one or two suggestions on this subject are considered necessary, particularly with reference to the age of the Portland Raised Beach.

The writer wishes to express his gratitude to Dr. H. H. Thomas for his great assistance in the petrological description of the pebbles; to Mr. E. H. Davison for advice on Cornish Rocks; to Mr. R. C. Spiller for much help both in the field and in the laboratory; to Dr. W. J. Arkell for advice on the nature of the local Corallian rocks; and especially to Professor W. J. Sollas for his invaluable encouragement and advice; also to Mr. G. C. Robson for important information concerning the non-marine mollusca.

II. Supply of Pebbles from External Sources.

It has been known for a long time that the pebbles both of the Portland Raised Beach and of the Chesil Bank include a few of distant origin in addition to the majority of the pebbles, which have been derived from more local sources. Before discussing how the "foreign" pebbles have been introduced into the present district, it will be as well to make one or two observations about those deposits from which these pebbles appear to have come.

Permian.—A certain type of porphyry is found as pebbles both in the Portland Raised Beach and in the Chesil Bank, although its frequency in both these deposits is very low, not more than 1 in 10,000 of the pebbles. It was pointed out to Sir J. Prestwich (1875, p. 67) [1] by Dr. Vicary that these pebbles could be matched in the Dawlish Breccia, and the present writer has collected specimens of this rock which are identical in all three deposits.

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[1] A list of the works to which reference is made will be found at the end of the paper, arranged in chronological order.

Bunter.—It has long been known that many of the quartzites and sandstones in the raised beach can be matched among the pebbles of the Budleigh Salterton Bed, but one or two facts appear to have escaped the observation of previous workers. For instance, whereas all the important quartzites in the Portland district can be matched in the Bunter, a large number of the Bunter types are unrepresented either in the raised beach or the Chesil Bank.

Keuper.—As far as the writer has seen, none of the pebbles of the Portland district have been derived either from the Dolomitic Conglomerate of North Somerset, or from any other English conglomerates younger than the Cretaceous.

Cretaceous and Tertiary.—Well-rounded pebbles of red cherty jasper, black chert and of vein quartz are found on the Chesil Bank, which appear to have been derived from the Cretaceous and Tertiary pebble beds of Devon and Dorset. There has been some doubt in the past as to whether pebbles of Budleigh type occur in the Tertiary pebble beds, but after long search the present writer failed to find a single one. It would appear, therefore, that the Bunter pebbles did not reach the Portland district through the Tertiary. It has been suggested by Clement Reid (1899, p. 31) that an explanation of the lack of Bunter material in these Tertiary gravels is to be found in " The Budleigh Salterton Bed being overlapped and hidden " by Cretaceous deposits at the time of the formation of these Tertiary gravels. That same writer, however, also noticed the presence of tourmalinized rocks among the Tertiary pebbles, so that part of Cornwall at least was uncovered at this Tertiary date.

From an examination of these deposits in Devon and Dorset, we can therefore arrive at the following conclusions about the origin of at least some of the " foreign " pebbles in the Quaternary of the Portland district :—

(1) That pebbles of porphyry entered the district direct from the Permian, and not to any extent, if at all, via the Bunter or the Tertiary, and that the Bunter pebbles also came direct without an intermediate Tertiary stage.

(2) That certain tourmalinized and other Palaeozoic rocks from Cornwall entered the Portland district in Tertiary times ; also it might be mentioned here that much flint was also derived from the Tertiary gravels, flint usually forming from 90 to 99 per cent of these deposits locally.

It can be seen then that up to Tertiary time the pebbles now found in the Portland district had not yet been collected together into one deposit, and we must now discuss at what geological date they became so assembled ? We have as yet no evidence as to whether this event might or might not have taken place in Miocene or in Pliocene times, but at least it is important to fix the earliest known date within the Quaternary at which these pebbles are found together ; this date will be shown to be that of the Portland Raised Beach.

III. ABRADED RIVER TERRACES.

Within the district under discussion the Quaternary deposits may be said to belong to three distinct facies :—

(*a*) Abraded river terraces.
(*b*) The Portland Raised Beach.
(*c*) The Head.

Of these the river terraces will be mentioned first, as they are believed to be older in part than the raised beach ; the reason why they are described as "abraded" will be given when describing the Head. The gravels associated with these terraces were mapped both by Prestwich (1875) and by the Geological Survey (1898), and appear on the existing geological map as "Plateau Gravels" and "Valley Gravels". Such a distinction appears to the present writer to be quite arbitrary, as no definition has been given as to the height at which the one should begin and the other end. For these deposits were seen in the field to be situated on flats in an otherwise rather sharply undulating country, and to occupy three definite levels, and it is therefore suggested here that we are dealing with the remains of three terraces. These are believed to be of fluviatile origin, partly because of their petrological character, and partly because no marine remains have ever been found in them. The suggestions here put forward are tentative, because at the present time (1928 and 1929) no sections of any depth were to be seen in these gravels, but their chief characteristics may be summarized thus, with the localities at which they are best developed, their heights determined by levelling, and their approximate area of outcrop.

Locality.	*Height above O.D.*	*Area in acres.*
Langton Herring . .	50 ft. (15 m.)	62
Wyke Wood . .	125 ft. (37 m.)	30
Fleet Common . .	220 ft. (66 m.)	20

It will be noticed that the area of the present outcrops of the deposits of each stage diminishes as the height increases, so that there is at least a suggestion that the Langton Herring Terrace is the youngest, and the Fleet Common Terrace the oldest of the three. The heights are measured above sea-level because there now exists no river in the district to which they can be referred, or which is large enough to form such deposits. It was believed by Osmond Fisher (1873, p. 481) that a comparatively large river once existed near the present course of the Fleet, which was subsequently captured by marine erosion, and the name Fleet River has been given to this ancient line of drainage in the Survey Memoir (1898, chap. xvi). The existing Fleet is the tidal backwater between the Chesil Bank and the mainland. It is believed by the present writer that these three terraces represent stages in the development of this river, and that the idea that their order of age corresponds with their order of height is confirmed by the fact that the patches of gravel belonging to the Langton Herring Terrace follow the line of the existing Fleet much more closely than those of the Wyke Wood Terrace. The gravels forming these terraces consist largely of local material, as in the field it was found that besides local Jurassic rocks, pebbles from the neighbouring Selbornian beds and from the Tertiary gravels of Black Down and of Bincombe Down were present, but no pebbles referable to the Bunter were found, although they are said to occur in the " Plateau Gravels " of the *Survey Memoir* (1898, p. 198). It may be assumed, then, that pebbles of Bunter type are non-existent or very rare in the deposits laid down by the Fleet River.

IV. THE PORTLAND RAISED BEACH.

The distribution of the raised beach material in the neighbourhood of Portland Bill is restricted to an area of about 100 acres, but fortunately there are many excellent sections showing the nature of the deposit. Only one of these is of critical importance, but before describing this, one or two general features of the raised beach must be noticed, the first being its altitude. Prestwich not only measured its height, but also showed that the platform on which it rests slopes from about 50 ft. down to about 20 ft. above present mean tide level, and the present writer not only confirmed these figures by levelling, but also came to the conclusion that the gradient is such as exists on any Recent shore. This is about 1 in 50 to 1 in 100 over most of the area, but steepens to 1 in 14 or even 1 in 11 near raised beach highwater mark, and during the field work this change of gradient was also noticed to correspond with the change of coarseness of the raised beach deposits, as in any Recent tidal zone. The important point to be noticed about these measurements of height is that it is possible to trace a " 50 ft. raised beach " down to an altitude of only 20 ft.

It might be suggested that this raised beach is not everywhere contemporaneous, and that there is a " 20 ft. raised beach " here as well as a " 50 ft. raised beach ". That this is not the case, however, can now be seen from the section exposed in the Bill Quarries, where marine gravels can be traced continuously from a height of 59 ft. down to 34 ft., these heights being measured above present highwater mark of ordinary spring tides. As the fauna of this raised beach has been discussed in detail in a separate paper (Baden-Powell 1930), this will not be done here, and it will be sufficient to say that the fauna at this locality confirms the idea that raised beach highwater mark was somewhere not lower than the present 40 ft. level. We have so far no means of knowing the tidal range at the time of the formation of the raised beach, but from a consideration of the outcrop as a whole, of the platform gradient, of the fauna and of the nature of deposition in different sections, a fair figure for the level of raised beach mean tide would be between 30 and 40 feet above present highwater mark, or in more general figures, 40 feet O.D. Until we know the tidal range of raised beach times, we cannot arrive at a very exact figure. It has been shown elsewhere (Baden-Powell, 1928) that the present climatic equivalent of the Portland raised beach fauna as a whole is to be found on the existing shores of Northern England and Southern Scotland, and this rather cold climate, previously mentioned by Sykes (1895) and Gwyn Jeffreys (1875) is therefore associated with the " 40 ft. raised beach " of this district.

The petrology of the raised beach pebbles is important as being the first known date at which the pebbles from the Dawlish Breccia, from the Budleigh Salterton Bed, and perhaps from the Tertiary, became assembled into one deposit in the Portland district. Although pebbles from these deposits are to be found, it is necessary to search for them, and the greater part of the deposit is made up of flint pebbles and of local limestone and chert. The general nature of the pebbles has already been noticed by Pengelly (1870), Prestwich (1875), and by the Geological Survey (1898), but during the course of field work the present writer found that the details described by the earlier investigators applied to one locality in the raised beach only, and that in practice the pebble content of the raised beach varies throughout its area of outcrop. The ancient coast-line runs approximately in a N.E.–S.W. direction, and it was found that at the S.W. end flint occupied some 90 per cent or more of the total content. This and the following percentages were determined by counting batches of a hundred pebbles each. When traced to the north-east along the raised beach shore-line, local Purbeck and Portland rocks are found to rise in frequency at the expense of the flint pebbles, until within a distance of about half a mile the percentage of flint pebbles drops down to 59, and further on, to only 40, most of the remaining 60 per cent being pebbles of local Jurassic limestones. As will be shown when discussing the Chesil Bank, this remarkable grading is also exactly reproduced at that end of the Recent deposit adjoining the Isle of Portland, and therefore whatever the cause of this petrological change along a sea beach, the phenomenon seen in the raised beach finds an exact petrological equivalent in the neighbouring Recent beach, to which, however, it is no longer joined.

Whereas some 99 per cent of the raised beach pebbles consist of flint or limestone, according to their position in the outcrop, the remaining 1 per cent is largely made up of the " foreign " pebbles derived from the beds discussed in Part II of this paper. These consist partly of quartzites and sandstones of Budleigh type, and partly of tourmalinized rocks of Cornish type, with rare porphyries of Dawlish type. Prestwich (1892, p. 296) expressed his doubt as to whether all the Cornish rocks were represented in the Budleigh Bed which are seen as pebbles in the raised beach, and one pebble was found by the present writer near the Bill of Portland, the origin of which is even less certain. This pebble, of which a slide has been cut, consists of a red granitic rock, and according to Dr. Thomas the minerals present are mainly perthitic orthoclase and quartz, with some albite and subordinate biotite; the rock shows no sign of tourmalinization. It is not easy to suggest a locality from which this pebble has been derived, and whereas it might have come from Cornwall, it does not immediately suggest any of the well-known Cornish types, and has at least travelled a long way before entering the Portland district. Mr. E. H. Davison, who has kindly examined the slide, is also doubtful of the Cornish origin of this pebble.

Prestwich was of opinion (1892, p. 296) that those pebbles in this raised beach of far-travelled origin which are not of Budleigh or Dawlish type were brought into the district by ice, and the idea seems quite plausible, but there are two points in this connection which are important.

(*a*) That the ice, presumably sea-ice, which carried the pebbles cannot be contemporaneous with the deposition of the raised beach in the strictest sense, as shown by the climatic equivalent of the contained mollusca.

(*b*) That since the foreign pebbles occur in the raised beach gravels, the date of the ice must therefore be pre-Raised beach.

The question now arises as to whether we can correlate this raised beach with any of the terraces of the River Fleet? The distance between the raised beach outcrop and the most southerly patch of gravel belonging to the Langton Herring Terrace is only about 5 miles. Since the height of this terrace is at 50 feet above present mean sea-level, the gradient usually allowed for such parts of a river valley would bring the level to about 20 feet above contemporaneous sea-level; that is, the mean height of the sea in Langton Herring times would be about 30 feet above its present height. The altitude of the Portland Raised Beach has already been given as about 40 feet, and it is therefore suggested here that the two are contemporaneous. A similar calculation for the Wyke Wood Terrace would require a height of some 80 feet for contemporaneous sea-level. It is considered that the local sequence up to the formation of the Portland Raised Beach is:—

	Fluviatile.	*Marine.*
Youngest.	Langton Herring.	Portland Raised Beach.
	Wyke Wood.	?
Oldest.	Fleet Common.	?
		Sea-ice at some pre-Raised Beach date.

It might be added that the evidence regarding the marine events during the Fleet Common–Wyke Wood stages of river development have been destroyed in the present district by subsequent marine erosion; also there is no evidence here as to whether the date of the occurrence of sea-ice coincides with one of these early stages. Fortunately both these questions can be answered by a study of the country further east (Selsey), but for the sake of brevity the matter in this paper must be restricted to the Portland district.

V. THE LOCAL HEAD.

As has been pointed out by Dewey (1913, p. 158), many sections in the raised beaches of Southern England show overlying non-marine deposits, and an excellent section of this nature is to be seen about a quarter of a mile N.W. of the Bill of Portland. This section was first described by Whitaker (1869, p. 497), and the sequence is :—

		ft.	in.
4.	Angular rubble, obscurely bedded	4	0
3.	Fine loam, with non-marine shells	4	0
2.	Sandy parting, with small fragments of *Littorina* and *Nassa*	0	2
1.	Well-rounded shingle, banked against a buried cliff, and arranged in alternate coarse and fine layers	9	10
	Platform of Jurassic limestone.		

Bed 1. The storm-beach part of the Portland Raised Beach, already described.

Bed 2 has the appearance of Blown Sand formed subsequent to the commencement of uplift of the raised beach.

Bed 3. A non-marine deposit, the complete fauna of which has been worked out by Bullen (1900, p. 286) in analytical form. According to his census the shells are, in order of frequency :—

	per cent.
Pupa muscorum (Linne)	42·0
Succinea oblonga (Drap)	25·0
Limnaea peregra (Linne)	11·0
L. truncatula (Muller)	8·0
Hygromia rufescens (Pennant)	5·0
Vallonia pulchella (Muller)	2·5
Helicella itala (Linne)	1·0
Hygromia hispida (Linne)	0·5
Cyclostoma elegans (Muller)	0·5
Pisidium Sp.	0·5
Helix Sp.	0·5
	96·5

An examination of this list shows that these forms cannot have lived together, as the assemblage found is ecologically impossible. Either we must assume that the deposit was formed in a fresh-water marsh, and that the terrestrial forms were washed down from surrounding drier ground, or, as is more likely from an examination of the section, the whole has been disturbed by the later formation of the head, and consists of a mixture of both marsh and dry terrestrial deposits. The shells as a whole could not stand a sub-arctic climate, and even have a general warm tendency, and on the whole the land shells indicate, as might be expected, proximity of the sea-shore.

Bed 4. May be described as typical Head, and consists mostly of angular fragments of Lower Purbeck rocks, although it also contains pockets of the loam, and also pieces of Cretaceous, Middle Purbeck, and other rocks no longer occurring on the Isle of Portland,

and it is even possible to find rounded Bunter pebbles in the head in this section. In short, there is little doubt that the head includes fragments of both the loam (Bed 3), and of the raised beach, in addition to the more common fragments of the local rock. Prestwich (1892, p. 278) mentions both marsh and terrestrial shells as occurring in the head at this locality, and these were presumably derived from Bed 3 of this section. The whole section is important because it shows clearly the relations between the raised beach and the overlying non-marine deposits.

A vertebrate fauna has been found in the head in other parts of the Portland district, although it has not yet been possible to confirm the identification of these earlier finds. Prestwich (1892, p. 277) has reported from near Encombe House a " trail of mixed gravel and brickearth " containing remains of *Elephas primigenius*, *Rhinoceras tichorhinus*, and " ? *Rangifer tarandus*, *Equus*, and *Bos* ". The same authority found *Elephas antiquus*, ? *E. primigenius*, " *Equus*, *Cervus*, and *Bos* " in fissures in some of the Portland quarries associated with head-like pebbles; Damon also reported (1884, p. 144) from fissures in these quarries *Rangifer tarandus*, *Bos urus*, and *Cervus giganteus*, and from Radipole, near Weymouth, teeth and bones of *Elephas primigenius*. Although none of these finds have been studied in late years, with one or two exceptions they convey a general impression of a sub-arctic fauna, a fact which is in keeping with our ideas of the way in which the Coombe Rock or Head are generally believed to have been formed.

In addition to the fauna of the head already mentioned as occurring in the section near the Bill of Portland, however, the fauna is not always sub-arctic in character, because at Chesilton Prestwich found (1892, p. 278) " at the base of the head " :—

Pupa muscorum (Linne).
Limnaea peregra (Muller).
Bithynia tentaculata (Linne).
Planorbis glaber (Jeffreys).

As has already been suggested by Prestwich, the apparent explanation of this contradictory nature of the fauna of the Head is to be found in the fact that it was possible for the shells to be preserved in " erratics " of frozen clay or loam during the formation of the Head under more or less arctic conditions. If this explanation is correct, the land- and fresh-water shells must be considered to be earlier in age than the Head itself, and such a derived origin explains the mixture of ecological types. Amongst the most notable features of the Head in this district are: the frequency of its occurrence, the fact that it is found at all altitudes, and that it almost always shows a slight shifting of the rock fragments across the boundaries of their original outcrop. Also, since the Head can be traced to existing sea-level, this deposit was formed during emergence rather than submergence of the land.

At the mouth of the Preston Valley, to the east of Weymouth, there is an interesting section which shows deposits which appear to be later than the Head. This section, resting on Oxford Clay, shows bedded silt and gravels, the former with *Littorina* and *Helix*, and contains flint which has presumably been derived from the local Head. It is by no means certain that the Head is everywhere contemporaneous in the Portland district, but no evidence has so far been found to the contrary, and in almost every section it has the appearance of being almost the last bed formed beneath the sub-soil.

Before summarizing the general local sequence, one other deposit must be mentioned which is at least earlier than the formation of the Chesil Bank in its present position, but which may be later than the formation of the Head. In 1929 the writer examined certain shallow workings which had been opened in the Chesil Bank shingle. These were situated on the N.E. face of the Bank, about 800 yards S.E. of the end of the existing Fleet. These workings had been carried beneath the base of the shingle, which was seen to rest on fine white sand. This sand is devoid of pebbles, and has the appearance of blown sand, and it is suggested that dunes could only have been formed at this point at a time when the Chesil Bank had not encroached to such a great extent on the Fleet Valley as is now the case, and also at a time when the land stood relatively higher than it does now. Blown sand has been mapped near this locality by the Geological Survey, without, however, any suggestion as to its age.

It seems, therefore, that we are justified in considering the local Quaternary sequence in the Portland district to be :—

Ht. of sea-level.	*Deposits.*	*Climate.*
7. Positive.	Preston Valley.	Temperate.
6. Negative.	Chesil Blown Sand	
5. Negative	Head	Sub-arctic.
4. ?	Loam	Temperate.
3. 40 ft. (12 m.)	Portland Raised Beach, Langton Herring Terrace.	Cold temperate.
2. 80 ft. (24 m.)	Wyke Wood Terrace	Sea-ice at some time prior to Stage 3.
1. 200 ft. (60 m.)	Fleet Common Terrace	

It might be remarked that in many of the inland sections in the Head, rock fragments appear to have been derived from the terraces of the Fleet River, and in fact the gravels of these terraces have been so frequently disturbed, at least in their upper layers, by the process of Head formation, that it is often difficult to tell whether a deposit should be classified as Head or as river gravel. It is for this reason that the terraces have been described as " abraded ".

Since the Portland Raised Beach is the earliest deposit in which the critical assemblage of pebbles discussed in this paper is known to have been collected together, the determination of the age of this raised beach is important, and its suggested position in the local Quaternary sequence can be seen from the above table. This table is perhaps slightly deceptive, since the appearance of these deposits in the field suggests that the time-value of the post-raised beach events is not so great as that of those events which occurred before the formation and uplift of the raised beach. This idea, that the 40 feet raised beach at Portland represents an intermediate rather than an early stage in the Quaternary history of this district, receives ample confirmation from a comparison with similar deposits round the Solent, which have been described recently, especially from the cultural point of view, by L. S. Palmer and J. H. Cooke (1923, p. 264). These authors definitely correlate the raised beach at Portland with that at Brighton (Portslade Station, at various heights below 50 feet O.D.), in which the marine fauna is also cold temperate.

VI. THE CHESIL BANK.

This digression from the account of the origin of the pebbles which eventually came to be assembled as the Chesil Bank has been necessary, in order to show the series of stages by which they became introduced into the Portland district during Quaternary time. The Chesil Bank may be described as the logical conclusion of the history of the pebbles which has been traced in this paper. No attempt will be made here to give a complete description of this deposit, since this has been done most exhaustively by Sir John Coode (1853, p. 520), but it is proposed to mention one or two points of dissension which have existed in the past concerning the origin of this Recent deposit. The essential points relating to the Chesil Bank on which all previous workers are agreed are :—

(*a*) That this beach stretches approximately in a N.W. to S.E. direction, in other words, that it faces S.W.

(*b*) That the pebbles are most distinctly graded, being small at the Bridport end of the beach, reaching maximum size near Chesilton and then rapidly diminishing again in the remaining few hundred yards of its length.

(*c*) That by far the most common pebbles are of flint and chert, and that other pebbles present are of Jurassic limestones, quartzites, and sandstones of Budleigh type and porphyry of Dawlish type. Some at least of the limestones are referable to the Isle of Portland.

(*d*) That along part of its length the Chesil Bank is separated from the mainland by the tidal backwater known as the Fleet, and it would appear that these shores have never been exposed to the full force of the waves which at present reach the exposed side of the Chesil Bank.

The main points of difficulty relating to these four features are :—

1. By what means did so many pebbles come to be assembled at this particular part of the existing coast ?

2. What alterations have taken place in the size or in the rearrangement of the pebbles since they arrived ?

Before answering these two questions, one or two remarks are necessary about paragraph (*c*) above, that is, about the petrology of the Chesil pebbles. As a whole, the Chesil Bank is just such a deposit as would be expected to result from a blending of the Portland Raised Beach material with the pebbles from the Fleet Terraces and the Head. In addition to these three sources of pebble supply, there is a slight admixture of local rocks from the Isle of Portland, but none from the Lias around Lyme Regis. The petrology of the pebbles show that, on the whole, they have been derived in much greater numbers from the drift than from the solid. Again, as in the raised beach itself, there is found to be lateral differentiation of the pebbles on the Chesil Bank ; for instance, the writer found that pebbles of vein quartz are absent from the Portland end of the Bank, and that they increase in numbers near Abbotsbury. Again, at the Chesilton end of the Bank, a series of analyses taken at 10 feet intervals along high water-mark, showed that the pebbles passed from 99 per cent Jurassic limestones and 1 per cent of normal Chesil type to 1 per cent Jurassic limestones and 99 per cent Chesil type, and that from this point north-westward the Chesil type remained dominant. It is suggested here that a study of the geological history of the Chesil pebbles and of the present wave-action in Lyme Bay supplies answers to the two questions which have been raised.

At the risk of being illogical, it will be most convenient to deal with the second of these questions first. The idea that the pebbles have become reduced in size during a process of travel along some miles of this beach at once suggests itself as an explanation of the remarkable grading which is to be seen, even by the most casual observer. Prestwich spoke of the " great wear of shingle as it travels from Chesilton to Abbotsbury " (1875, p. 76), and from a series of observations made by the present writer at intervals along the Chesil Bank, this " great wear " appears to describe what happens to the pebbles of limestone as they travel away from the Isle of Portland, but it must be remembered that, hard as the Portland stones are, they are the softest rocks relative to the others forming the Chesil pebbles. Dealing with all the pebbles, Mellard Reade (1875) asked during the discussion on Prestwich's paper what can have been the original size of the pebbles, if they are worn down from a diameter of several inches to the " size of a bean " in travelling along the Chesil Bank, and in a subsequent letter to *Nature*, Col. Greenwood (1875, p. 386) pointed out that the shingle between artificial groynes becomes graded, and that no one would suggest attrition as the cause in a few yards of beach. If, therefore, grading by attrition applies to the limestone pebbles, we must look for some other explanation for the grading of the harder flint and quartzites.

Prestwich (1875, p. 76) pointed out that the pebbles were already arranged in alternate layers of coarse and fine material in the raised beach (see the section in the present paper), so that when the Chesil Bank came to be formed, it was already supplied with pebbles varying greatly in size, and by comparison with the Budleigh pebbles the present writer is convinced that the quartzites at least had reached the degree of rounding seen on the Chesil Bank by the time they were incorporated in the raised beach, but we are still faced with the problem as to how the various sized pebbles became segregated to different parts of the beach. Without entering into a lengthy discussion on the direction of the waves which play a part in rearranging the shingle it was shown by Prestwich (1875, p. 111) that a prevalent wave-direction from S.W.$\frac{1}{2}$W. would produce N.W. to S.E. travel of the shingle, whereas prevalent S.S.W. waves would cause the shingle to travel in the opposite direction, that is, from S.E. to N.W., and that " the difference was not great; but was sufficient to turn the balance ". Since the waves come from both these directions during the course of the year, it can be seen that the shingle travels both ways along the bank.

But such an explanation is incomplete without a consideration of the size of the waves, an idea which was first introduced by Dr. Vaughan Cornish (1898). His observations led him to the conclusion that " the largest waves converge on Chesilton from both sides ", and according to his work the largest pebbles are of necessity moved by the largest waves. The smaller waves move away from Chesilton and are only capable of moving the smaller pebbles. He sums up his ideas by suggesting that (*Waves of the Sea*, p. 193) " the secret of the gradation of shingle upon beaches sheltered at one end from large waves is that whilst both large and small pebbles travel in one direction before the big waves which come with the great length of fetch, only the small pebbles are driven back by the small waves which come from the small length of fetch ". As long ago as 1853 Sir John Murray suggested, during the debate on Sir John Coode's paper (1853, p. 550), that the larger pebbles may " remain at Chesilton, whilst the smaller ones travel westwards ", thus introducing the idea that the direction of travel of the small pebbles is not the same as that of the large ones. It might be added that this grading of the shingle explains one or two points of interest concerning the distribution of the different kinds of pebbles on the Chesil Bank: for instance, it was found by the present writer that pebbles of vein quartz are absent in the beach material near Chesilton, whereas they occur on other parts of the beach, and it is suggested that the size of the original quartz pebbles, as found at Budleigh, are limited to a maximum diameter which is less than that of the quartzites, and that the vein quartz pebbles are therefore not found on that part of the beach where grading has collected the largest pebbles only. This gradual exclusion of the vein quartz pebbles by grading was traced by the writer over some miles of the Chesil Bank, by counting samples of shingle at regular intervals.

We can now return to the first of the two questions: How did so many pebbles come to be assembled at this particular part of the Recent coast? It is suggested that as our knowledge of the Quaternary events of the district increases in detail, so the difficulties of "explaining" the Chesil Bank disappear. The counting of pebbles at Dawlish, Budleigh Salterton, Portland Bill, and on the Chesil Bank, has convinced the writer that those pebble types in the older deposits which should be expected in the raised beach, but which are not found there, are precisely the same types which fail to turn up in the Chesil Bank, and that we must therefore consider that most of the Chesil pebbles came from the raised beach, and not, as has been suggested, from the floor of Lyme Bay. We can now summarize the history of the Chesil pebbles thus:—

(1) That pebbles have been derived independently from the Permian, Trias, Cretaceous, and Tertiary deposits of Devon and Dorset, together with a few Cornish pebbles, the more distant of these probably having been brought by sea-ice at an early Quaternary date.

(2) That these pebbles are first seen assembled in one deposit in the Portland Raised Beach.

(3) That the raised beach pebbles became mixed with those of the terraces of the extinct Fleet River, when the Fleet valley was captured by marine erosion, thus forming the Chesil Bank, an event which took place at a late Quaternary date, after the formation of the Head.

(4) That the pebbles of the Chesil Bank are now sorted by the action of sea-waves, but that the harder pebbles do not suffer much from attrition, although the relatively softer limestone pebbles may become so reduced.

(5) That the shape of the existing Fleet is determined partly by the curve of the Chesil Bank as arranged by the direction of the waves crossing Lyme Bay, and partly by the shape of what remains of the left bank of the valley of the Fleet River at the last stage of its development before being captured by the sea. That this stage was later than the formation of the Head, because that deposit reaches sea-level along the shores of the existing Fleet, and it is quite possible that the ancient sand dunes underlying part of the Chesil Bank were one of the factors which kept the sea from invading the Fleet valley at its south-eastern end.

(6) That this part of the Dorset coast is typical both of submergence and emergence, as shown by a study of the local raised beach and of the later history of the Fleet River and conditions under which the Head was formed.

(7) That the Chesil Bank is a mature marine deposit; that is, that it is not being added to to any appreciable extent at the present time. This conclusion is in agreement with those reached by

Dr. Vaughan Cornish (1898) and with the evidence given by Sir A. Strahan (1907, Question 3646) and by Mr. Clement Reid (1907, Question 2527), before the Royal Commission on Coast Erosion.

It might be added that the conclusions here reached are only intended to have a local significance, since the data on which they depend is essentially local. Nevertheless it is impossible to escape from the conclusion that in many if not all parts of Britain the shore deposits have been extensively derived from the drift, and that an intimate knowledge of the drift in any locality is indispensable to a proper understanding of the supply of material to a Recent beach.

LIST OF REFERENCES.

1853. Sir J. Coode. *Proc. Inst. Civ. Eng.*, vol. xii, p. 520.
1869. W. Whitaker. Geol. Mag., Vol. VII, p. 438.
1870. W. Pengelly. *Trans. Devon Assoc.*, vol. iv, p. 195.
1873. Rev. O. Fisher. Geol. Mag., Vol. X, p. 481.
1875. Col. Greenwood. *Nature*, vol. xi, p. 386.
1875. J. Gwyn Jeffreys. *Quart. Journ. Geol. Soc.*, vol. xxxi, p. 53.
1875. Sir J. Prestwich. *Proc. Inst. Civ. Eng.*, vol. xl, p. 67.
1884. R. Damon. *Geology of Weymouth and Portland*, 2nd ed., p. 144.
1892. Sir J. Prestwich. *Quart. Journ. Geol. Soc.*, vol. xlviii, p. 227.
1895. R. E. Sykes. *Proc. Dorset Field Club*, vol. xvi, p. 171.
1898. Sir A. Strahan. *Mem. Geol. Surv.*, "Geology of the Isle of Purbeck and Weymouth," chapter xiv.
1898. Dr. Vaughan Cornish. *Geog. Journ.*, vol. xi, p. 628.
1899. Clement Reid. *Mem. Geol. Survey*, "Dorchester," p. 31.
1900. Rev. R. Ashington Bullen. Geol. Mag., p. 286.
1907. *Royal Commission on Coast Erosion*, vol. ii.
1911. Dr. Vaughan Cornish. *Waves of the Sea*, p. 193.
1913. H. Dewey. Geol. Mag., p. 158.
1923. L. S. Palmer and J. H. Cooke. *Proc. Geol. Ass.*, vol. xxxiv, part iv, p. 264.
1928. D. Baden-Powell. Union Géographique Internationale. *Report of Commission on Pliocene and Pleistocene Terraces*, p. 110.
1930. D. Baden-Powell. *Proc. Malacological Soc.*, vol. xix, part ii, July.

An Association of Anthophyllite and Enstatite.

By F. Coles Phillips, M.A., Fellow of Corpus Christi College, Cambridge.

Of the naturally occurring forms of (Mg, Fe) SiO_3, only two are of any great petrological importance. Rhombic pyroxenes of the enstatite-hypersthene series are common in many igneous rocks and in the metamorphic derivatives of these and of sediments. Members of the anthophyllite group of rhombic amphiboles are of much more restricted occurrence, being practically confined to crystalline schists and metasomatic products. The stability relationships of these forms and of the rarer monoclinic clinoenstatite and kupfferite[1] were originally investigated by Allen, Wright, and Clement.[2] Enstatite was obtained by crystallizing a glass below 1100° C., and anthophyllite by very rapid cooling from a melt at about 1600° C. Some uncertainty still exists, but it is clear that at least under normal pressure clinoenstatite is the only stable form.[3]

It becomes of interest, therefore, to record any association of these various forms in nature. The development of anthophyllite in the Shetland Islands is well-known from the description by Heddle,[4] and recently the writer has described the geological nature of the occurrence.[5] Many of the slides cut from material then collected show extensive development of pyroxene. This feature was originally noticed by Lacroix,[6] but as his brief account does not seem to have been absorbed into the literature it is felt that a detailed description based on all the material available would be of value. This includes slices cut from some of Heddle's own material, and the writer is indebted to Dr. Harker for the loan of these.

The anthophyllite occurs in elongated crystals with a lath-shaped habit and a length of 1 to 2 inches in the more massive specimens, passing into a more acicular habit of smaller average dimensions in the true schists. In cross-sections the prismatic cleavages are prominent. Vertical sections show a good cleavage which in several measured instances proved to be (010), and an irregular parting parallel to the base ; the crystals are always irregularly terminated. The optical orientation is that usual in anthophyllite, $X = \alpha$, $Y = \beta$ $Z = \gamma$, the refractive index γ determined by immersion $= 1{\cdot}640$, the optical sign negative with 2V (in several cases measured on the universal stage) ranging from 79° to 84°. Heddle's analysis[7] shows only 4·5 per cent Al_2O_3 for the rock, but the influence of both FeO and Al_2O_3 on the refractive indices and optic sign of this group is not fully determined. Bowen[8] gives $\gamma = 1{\cdot}6404$, and a negative sign for Penfield's material from Franklin, N.C., which is practically non-aluminous. A few vertical sections of anthophyllite show an intergrowth with other material, indistinguishable from it in ordinary light, but revealing between crossed nicols apparent monoclinic symmetry and extinction from the vertical cleavage up to 16°. Sketches of two such crystals are given in Fig. 1: occasionally oblique sections show distinct zonary extinction. The exact nature of these intergrowths could not be determined, and they are of rather exceptional occurrence. It may be hazarded, however, that they represent small amounts of amphibole of cummingtonite or tremolite affinities.

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[1] It seems desirable to apply the name kupfferite to the monoclinic form of amphibole, the end-member of the cummingtonite series, in accordance with the original usage by Kokscharow, and that followed by Hintze, Dana-Ford and others. The Carnegie Institute workers apply it to the magnesian end-member of the anthophyllite series.

[2] *A.J.S.*, **4**, xxii, 1906 385–438.

[3] W. Eitel, *Wissenschaft. Forschungsber.*, *Naturwiss. Reihe*, 1925, xiii, 44 ; *Phys. Chem. der Silikate*, Leipzig, 1929, 290.

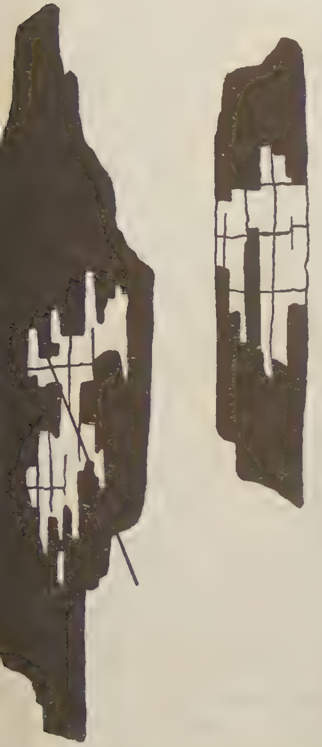
[4] *Min. Mag.*, iii, 1880, 21.

[5] *Q.J.G.S.*, lxxxiii, 1927, 642–4.

[6] *Compt. Rend.*, cii, 1886, 1332.

[7] Op. cit., p. 21. This analysis is given as of anthophyllite, but since slides of his own material show considerable amounts of pyroxene, it may reasonably be assumed that no separation was carried out, and that the analysis is that of an anthophyllite-pyroxene rock.

[8] *Journ. Wash. Acad. Sci.*, x, 1920, 413.



1.—Intergrowths in rhombic amphibole. × 75, app.

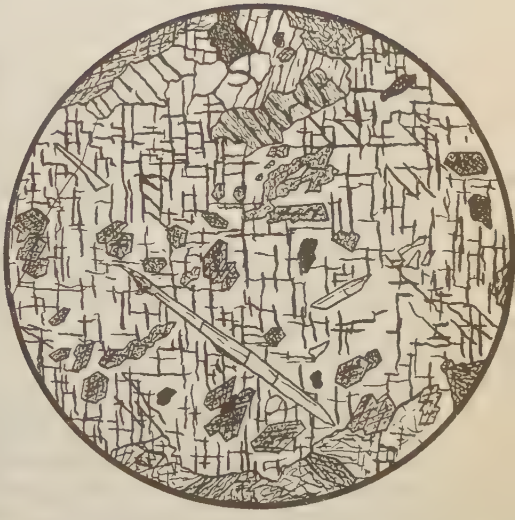


Fig. 2.—Basal section of pyroxene, showing idiomorphic inclusions of amphibole. × 32, app.

The colourless pyroxene is separable from the amphibole by several characteristics. The prevailing habit is much less elongated. In basal sections the prismatic cleavages are, of course, distinctive: in vertical sections the cleavage traces are usually much more pronounced than in the amphibole. The higher double refraction of the anthophyllite (Lacroix gives the figure ·023) yields in slices of conventional thickness polarization-tints up to the top of the first order, whereas the pyroxene never rises above a pale yellowish-white. The optic sign is positive, 2V in measured instances 68° to 74°. Lacroix states [1] that it is also easy to distinguish the pyroxene by the extinction-angles from 0° to 35° in the zone (100) (010). The presence of a monoclinic pyroxene in a rock of this composition would be of special interest, as it must of necessity be a clinoenstatite or clinohypersthene. Several sections were, therefore, carefully determined on the universal stage, but proved to be in every case rhombic enstatite. This accords with the prevalent straight extinction in thin slices; oblique extinctions are observed occasionally from apparent vertical cleavages owing to the fairly high optic axial angle, and this is true also of the larger sections of the rhombic amphibole, whereas in those rocks in which the anthophyllite is finely acicular and elongated sections must be nearly truly vertical the extinctions are rigidly straight.

Other associated minerals in smaller quantity include a chlorite in well-shaped laths showing a good cleavage, ferruginous matter, and occasional serpentinous aggregates. The anthophyllite shows a variable degree of alteration to talc, and in the more schistose examples the acicular crystals are associated with considerable quantities of this mineral in a finely divided state. A few slices show patches of typical mesh-structure with islands now composed of small anthophyllite-needles.

The paragenesis of anthophyllite and enstatite might conceivably be explained in more than one way. The pyroxene is characteristic of a higher temperature-range than the amphibole, and the occurrence is closely associated with igneous intrusions.[2] From the manner of association seen in thin slices the enstatite is of later formation than the anthophyllite, large crystals of the former wrapping round and enclosing the latter (Fig. 2). There is little evidence, however, that the pyroxene has formed at the expense of the amphibole; large basal sections of enstatite enclose many small cross-sections of anthophyllite, but although there is a general tendency to parallelism of the vertical axes these idiomorphic cross-sections are otherwise irregularly orientated and never suggest that they represent relics of former larger crystals. Natural anthophyllite is characteristically a stress-mineral, and it seems reasonable to suggest that during the genesis of the rock the shearing-stress declined gradually, probably concurrently with rising temperature until below the value appropriate to the formation of amphibole.

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[1] Op. cit., p. 1332.
[2] F. Coles Phillips, op. cit., p. 642.

The Lithology of the Inferior Oolite, Dundry (North Somerset).

By D. S. Cleak, B.Sc.

THE petrology of the Mid-Jurassic sands in the south-west of England has been described both by Professor P. G. H. Boswell[1] and Dr. J. G. A. Skerl.[2] Professor Boswell has dealt with the Toarcian-Aalenian sands from various localities between Cheltenham and the Dorset coast; Dr. Skerl with certain Bajocian and Bathonian beds in the North Cotteswolds. The present paper gives some account of the lithology and terrigenous minerals of the oolitic limestones of Dundry, an area approximately midway between the Cheltenham region and the south coast. Dundry Hill is an isolated patch of Oolite some 8 miles west of the Bath Hills, and Dundry village, which stands on its crest, is 5 miles south of Bristol. The geology and palaeontology of the area have received the attention of many geologists from the time of Conybeare and Phillips,[3] but here only the work of S. S. Buckman and E. Wilson[4] need be referred to, since these authors fully review the previous literature. Buckman and Wilson described the rocks in great detail, and their classification of the strata has been utilized here.

LITHOLOGY.

The Inferior Oolite at Dundry consists entirely of limestones—chiefly oolitic—which differ from one another more in their fossil suites than in their physical characters. Most of them are more or less " iron-shot ", i.e. contain ooliths of limonite in an unaltered calcite matrix. This character, however, is particularly well developed in the limestone of the *sauzei* zone, known as the " Iron-shot Bed ". The bed is well exposed in the Southern Main Road Quarry.[5] It is a hard, compact, pink to yellow limestone, about 1 foot thick. The limonite ooliths are scattered throughout the rock in a matrix consisting of calcite but containing some quartz grains, a few of the ooliths, but only a few, containing a quartz grain as a nucleus. Some grains show a concentric structure, but most are structureless. In all of them, however, the outer part is darker than the centre. Whilst all the ooliths are replaced by limonite, the matrix is quite unaffected. The general lithological characters of the beds are given in the following table :—

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[1] " The Petrography of the Sands of the Upper Lias and Lower Inferior Oolite in the West of England," Geol. Mag., Vol. LXI, 1924, pp. 246–64.

[2] " The Petrography of some Jurassic ' Sands ' from the North Cotteswolds," *Proc. Cotteswold Nat. Field Club*, vol. xxii, 2, 1925, pp. 153–9.

[3] *Geology of England and Wales*, 1822, p. 236.

[4] " Dundry Hill: its Upper Portion, or the Beds marked as Inferior Oolite (*g* 5) in the maps of the Geological Survey," *Q.J.G.S.*, vol. lii, 1896, pp. 669–720, and " The Geological Structure of the Upper Portion of Dundry Hill ", *Proc. Bristol Nat. Soc.*, New Ser., vol. viii, pt. 2, 1895–7, pp. 188–231.

[5] The quarries from which my materal was collected were (1) Church Quarry, south side of the village 100 yards S.W. of Dundry Church; (2) Southern Main Road Quarry, on the main road between Dundry and Chew Stoke, rather more than a mile from the former; (3) Rackledown Quarry on Rackledown Farm, half a mile east of the Dundry–Chew Stoke road.

	Zone.	*Name of Bed.*	*Lithology.*
BATHONIAN.	*Post-garantianae.*	"Coralline bed."	Marly and crystalline limestone with corals.
		"Dundry Freestone."	Grey to white compact freestone in Church Quarry, formerly much used for building, but deteriorates, passing into soft ragstone in other parts of the hill, i.e. South Main Road Quarry. Thin sections show that the freestone is crowded with organic remains, chiefly comminuted shell fragments and crinoid stems, with much developed crystalline calcite.
	garantianae.		Grey, compact, crystalline limestone "Conglomeratic bed" of Maes Knoll which contains derived pieces of sandstone, etc.
BAJOCIAN.	*sauzei.*	"Ironshot Oolite."	This bed, which has been already described, has the upper surface planed off and bored.
	Witchellia.	"Upper White Ironshot."	White, compact ironshot limestone.
	Sonniniae.	"Lower White Ironshot."	Hard, compact, pinkish crystalline limestones with marly partings.
	discitae. *concavi.*	Grey limestones and marls.	
	bradfordensis. *murchisonae.*		Hard, compact, pinkish limestones. The beds of the *murchisonae* zone are specially hard, massive and resistant to weathering.
	opalini.		Hard, massive, pink, crystalline limestones, arenaceous and iron-stained but without limonite ooliths.
	aalensis.		Not exposed in quarries from which the material was collected.

INSOLUBLE RESIDUES.

(*a*) *Petrographical Methods.*

For the purposes of examination several unweathered specimens of the limestone were collected from different points on the same horizon and were broken into small pieces. The material so obtained was crushed and sieved into three grades of 30, 60, and 90 mesh. Each grade was then washed and dissolved in concentrated hydrochloric acid. The residue was then boiled with acid to remove iron, filtered, washed, and dried. The heavy minerals were separated by the bromoform method and mounted in Canada balsam in the usual manner. In most cases a quantitative estimation was made, the various limestones showing a wide range of arenaceous content. A proportion of the sieved material of each of the limestones examined was set aside after washing and carefully dried. This material was not treated with acid, but immediately subjected to the bromoform separation to ascertain the presence or absence of apatite. Results in this case were not satisfactory owing to the great degree of iron staining of the mineral grains and consequent difficulty of examination.

(*b*) *Mineralogy.*

In all the residues, silica in the form of detrital quartz is the most abundant constituent. The grains vary greatly in size, being, on the whole, largest in the lower zones where the beds are most arenaceous. The average grain size in the lower zones is 0·25 to 0·3 mm., in the freestone about 0·1 mm. On the whole the detrital quartz is distinctly sub-angular. The grains are usually clear but sometimes show abundance of minute inclusions which may be arranged in rows or scattered through the grain. Zircon is fairly plentiful in all the residues and usually occurs in well-rounded grains (0·08 mm.) but short stout prisms, and long needle-like crystals are also fairly plentiful (0·18 mm.). These show the characteristic high refractive index, absence of colour, and frequent presence of inclusions. Tourmaline, grey and brown in colour, occurs fairly abundantly in most of the residues. Its habit is usually in angular, platy fragments, but prismatic grains are common. It is characterized by its high pleochroism and low polarization colours. Pink to colourless garnets showing angular to sub-angular outlines are common.

Rutile is found in all the sediments, but is most abundant in the "Ironshot bed". It occurs in well-rounded yellowish to brownish red grains. One or two geniculate twinned crystals were observed. The iron oxides chiefly consist of magnetite which occurs in opaque black grains varying in size and angularity, but haematite, leucoxene, and pyrites are common, haematite and leuxocene especially so, in the *sauzei* zone. The leucoxene is characterized by its colour in reflected light, and by the pitted surface of the grains, and the pyrites by often occurring in small cubic crystals.

Muscovite occurs in all the residues in colourless platy fragments showing a low refractive index and low birefringence.

Kyanite is only moderately common, occurring chiefly in the lower zones. The crystals are colourless but birefringence is high. Occurring with the quartz in the light crop is a considerable amount of felspar in each of the residues. Low refractive index and much weathered surfaces characterize this mineral.

I have tabulated below the details concerning the insoluble minerals of the successive beds :—

Zones.	*Minerals present.*	*Residue Percentage.*	*Average diameter of quartz grains.*
Post-garantianae	The amount of residue from the Dundry Freestone was too small to make bromoform separation possible. The chief constituent of the insoluble material was quartz.	0·11	mm. 0·05–01
garantianae.	The insoluble residue is small and chiefly quartz. The grains are on the average larger than those in the other beds and show inclusions which are often arranged in definite rows.	1·9	0·3
sauzei.	The detrital quartz grains vary much in size (0·1 to 0·45 mm.) but the average grade is about 0·25 mm. Felspars in grains of an average diameter of 0·25 mm. are fairly abundant ; they show cleavage and much weathered surfaces. Rutile plentiful.	6·13	0·25
Witchellia *Sonniniae* *discites* *concavi*	Quartz is the chief constituent of the residues, but the grains are much smaller than in the zones below and more angular and clear. Felspars are present and show much weathered characters, whilst the rarer minerals are on the whole the same as found in the lower zones. There is predominence of the iron oxides, chiefly magnetite. Zircon as short prisms and as small well-rounded grains is characteristic of these zones. Garnet, tourmaline, rutile, pyrite, and muscovite are present.	3·2 5·7	0·20 0·12
bradfordensis *murchisonae* *opalini*	Detrital quartz is by far the commonest constituent of these beds, and forms the bulk of the residue. It occurs in well-rounded to subangular grains of a fairly uniform size (0·2 mm.). Strongly pleochroic tourmaline, zircon, garnet and iron oxides form the bulk of the heavier minerals; rutile, muscovite, kyanite and pyrite are also present.	5·42 4·7	0·25 0·2

CONCLUDING REMARKS.

S. S. Buckman (1889)[1] has shown that the Inferior Oolite of Dundry below the *Garantianae* zone, both in its lithology and fauna, differs markedly from the equivalent beds of Bath, Doulting, and the Cotteswolds, but agrees very closely indeed with those of Dorset. From this he argues that the Dundry area was separated from the Bath, Doulting, Cotteswold region by a land ridge ("The Tortworth Ridge") during most of Bajocian times, but was connected with the Dorset area throughout the period by a channel round the western end of the Mendips. Professor Boswell has proved that the mineral suites of Dorset and the Cotteswolds differ, and it is interesting to note that the detrital minerals of the Dundry limestones show a closer similarity to the minerals of the Cotteswolds than to those of the southern area.

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[1] "The Relationship of the Dundry with the Dorset-Somerset and Cotteswold Areas during part of the Jurassic Period," *Proc. Cotteswold Nat. Field Club*, vol. ix, pp. 274–387.

Whatever may have been the ultimate source of the mineral particles in the Dundry limestones and in the Cotteswold sandy deposits—possibly the Armorican massif south of the present limits of these islands—it is reasonable to assume in both cases that the immediate origin was the adjacent land ridge. This can well explain the similarity between the mineral suites of the two areas and is in harmony with Buckman's views on the local palaeogeography of the period.

In conclusion, I wish to thank Professor S. H. Reynolds for suggesting the subject of investigation, for his friendly advice, and for the interest he has shown in the work; Dr. Stanley Smith for help and suggestions; Mr. J. W. Tutcher for freely placing at my service his unrivalled knowledge of the Jurassic rocks; and Dr. F. S. Wallis for his aid and supervision throughout.

A Note on the Turoka Series of East Africa and the Nachipere Beds of Nyasaland.

By John Parkinson, Sc.D.

DR. DIXEY, in his interesting paper on the "Geology of the Lower Shire-Zambezi Area" in the February number, remarks upon the resemblance shown by his Nachipere Series (first mentioned in the Annual Report for 1926, p. 6) to the series of completely metamorphosed sediments described by me under the name "Turoka Series" in 1913 (*Quart. Jour. Geol. Soc.*, lxix, p. 534).

The type locality for the latter is the Turoka River, S. of the Magadi Railway in the southern part of Kenya. (See Sketch-map.) In 1914–15, a journey from the Marsabit volcano in the Northern Frontier Province to Archer's Post, showed again a series of completely metamorphosed sediments, which were traversed for a distance of about 80 miles from N. to S., a direction slightly oblique to the dominant strike of the planes of foliation. Amongst these, but especially to the S., orthogneisses are of frequent occurrence, and doubtless, contaminated and hybrid rocks connect the two. The whole is indistinguishable from the Turoka sediments and associated rocks of the S.

With one exception, a large mass of olivine-gabbro west of the Lorian swamp, there are no intrusions known to me either in the Turoka area itself or in the triangle, Archer's Post-Marsabit-Lorian, later than the orthogneisses which I consider analogous to the Laurentian gneiss of Canada. The gap between these two districts, the Northern Frontier Province and the Turoka River, of the order of 180 miles, has been partially filled by Gregory, Hobley, Maufe and others. Recent traverses in the Suk Hills by Mr. Vincent Glenday (*Quart. Jour. Geol. Soc.*, lxxxii, p. 586, and lxxxiii, p. 790) and by myself via Kacheliba to the Napao Pass show a westward extension of these sediments. About 15 miles S. of the Swam (Turkwal) River at Kacheliba bridge, a gabbro mass is intrusive into a biotite-gneiss which is the dominant rock as far as Lokipernek. Further work will probably show such bathyliths are characteristic of this part of the Province and they may be contemporaneous with Sekerr, a mountain nearly 11,000 feet high in the centre of the Suk Hills. This does not alter the conclusion that the recrystallization of the Turoka Beds cannot be ascribed to local action. The Sekerr intrusion does not appear to have affected appreciably the rocks in its vicinity which had earlier reached their present state of crystallization. There is no doubt that the Series can be extended into Tanganyika Territory at least as far south as Morogoro (Uluguru region) where Teale and Tippelskirch record kyanite, sillimanite, garnet, and scapolite schists and gneisses together with crystalline limestones. At Masasi, 260 miles roughly south of Morogoro, I have noted typical "inselberge" of well-foliated biotite-gneiss, its micaceous bands alternating with others of a more quartzo-felspathic nature. Such rocks are familiar in the north. On the motor road to Newala, the outcrop of crystalline limestones with felspathic quartzites both containing graphite, together with garnet-bearing rocks characteristic of the district but not seen by me in situ, indicate the Turoka Series and are probably to be correlated with the very garnetiferous gneisses containing much graphite outcropping to the west of, and a short distance from, the Cretaceous outlier of Tendaguru. It is at least safe to take the length of the outcrop of the Turoka Series, naturally with sundry breaks, at about 700 miles, if Masasi is included nearly 1,000, while the width across the Suk Hills to Buttellu, where typical sections can be studied, is about 320 miles. Throughout this area no passage has yet been found to sediments retaining obvious clastic structure, with the possible exception of the Kateruk Series in N.E. Suk which shows a somewhat less degree of metamorphism, but is nevertheless completely recrystallized.

In a Summary of Conclusions regarding the history of the Turoka rocks, it was pointed out (*Quart. Jour. Geol. Soc.*, 1926, lxxxii, pp. 608–9) that the metamorphism of these sediments was continental in character, that evidence existed that ortho-gneisses of the Turkwal type were the cause of the reconstruction, and a

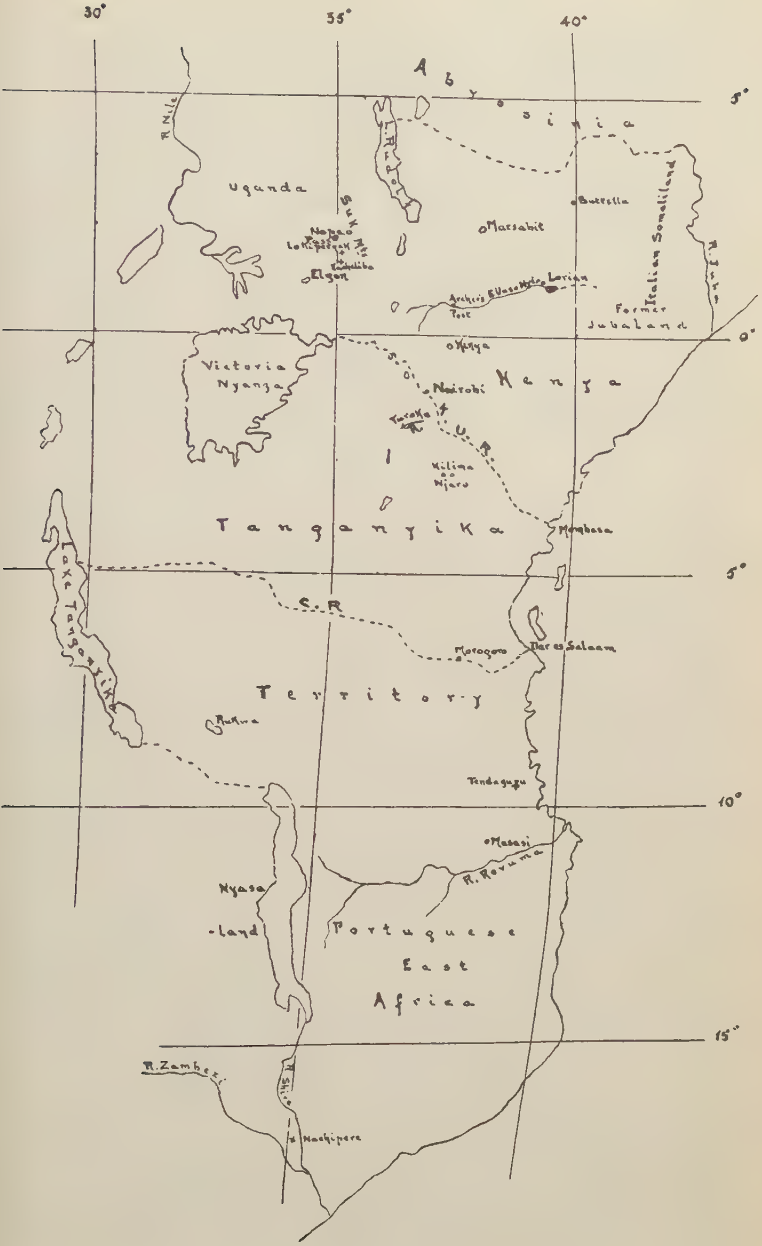

FIG. 1.—Sketch-map of E. Africa.

veiled comparison was drawn between the Kenya rocks and the oldest elements forming the Canadian Shield, that is the Loganian System, and the intrusive Laurentian bathyliths. It is to be expected that, should a lesser degree of metamorphism be found eventually in indubitable members of the Turoka Series, such clastic structures as are still obvious would occur only in an insignificant proportion of the rocks as a whole. The invasion of the " Basement Schists " of Northern Rhodesia by the M'Kushi Gneissose Granite, described recently by Dr. Austen Bancroft (*Internat. Geol. Congress. Guide Book Excursion*, C. 22, p. 3) would appear to be strictly comparable to the early history of the oldest rocks of Kenya. In the same paper (p. 4) Dr. Bancroft mentions the occurrence of " roof pendants " of greatly indurated and silicified rocks in the midst of granitoid gneiss. The existence of roof pendants implies the possibility of stoped-off blocks subsiding in the viscous magma, a possibility the writer has had long in mind when considering the structure of the Colony, and he would put forward the suggestion that the high angles and the contortion of the foliation planes may be due to some extent to tilting and collapse during this process, and not altogether to later or contemporaneous compressional stress, which of course occurs. It is of interest to note that on the traverse to Archer's Post mentioned, out of twenty-four observations taken of the foliation strike and chosen to represent principal directions, sixteen lay between 330° and 5°, a mean angle of 347° (angles are given as read by a prismatic compass), two lying to the W. and six to the E. of the containing angles. In the same way out of twenty-nine observations taken on the Turoka River twenty-one fell between 317° and 0° (mean angle 338°), four being to the E. and four to the W. of these. Between we have Maufe's determination of 338° for the gneisses near the railway (*Col. Rep.*, *Miscell.*, No. 45, 1908, p. 19). On the other hand the para-schists of Ajow had a strike of 44° (four observations); at Buttellu, also para-schists, 15 miles to the S.E., the mean strike was 310°. The two were thus almost at right angles. West of Ajow, the ortho-gneisses trended almost N. and S. At Archer's Post and E. and W. along the S. Uaso Nyiro, the foliation strikes varied greatly, swinging generally to the E. Here also the rocks were principally orthogneisses (see *Col. Rep.*, *Miscell.*, No. 91, 1920, p. 20). A belt of somewhat irregular foliation is accordingly interpolated between two areas of uniformity. The Nachipere Series, on the contrary, has had a different " intrusive history ", the metamorphism has been intensified, if not inaugurated by late plutonic magmas of various kinds, its original members are still plainly and characteristically recognizable as " a group of conglomerates and arkoses, together with argillaceous, calcareous and carbonaceous beds ". The coarse conglomerates contain, in the type locality, " well-rounded boulders up to two feet in length " (*Nyasaland Geol. Sur. Rep.*, 1928, p. 10) of various gneisses, " felspathic, micaceous and hornblendic . . . apparently of igneous origin ".

Unless definite evidence exists to the contrary, this, in my opinion, precludes them from inclusion in the Turoka Series. Moreover, a " close comparison " is drawn between the Nachipere Series and the Mafingi Beds. The latter, first described by Andrew and Bailey, are estimated by Dr. Dixey to be at least 10,000 feet thick and consist of " quartzites, sandstones and grits, together with their metamorphic representatives " (*Ann. Rep.* for 1928, App., p. 18). Here, however, in N. Nyasa, the degree of metamorphism varies rapidly and " greatly from place to place ", producing quartz and quartz-mica-schists.

It appears that the grade of metamorphism is not high, and perhaps a heavy mineral analysis, failing pebbles from a conglomerate, would aid in determining from what types of rock they were derived. As it stands the history of both series would seem to have been different from that of the Turoka, hence I should prefer to place the Nachipere and the Mafingi Series in a subdivision of the pre-Cambrian younger than the former.

Sedgwick Museum Notes: The Contacts of the Threlkeld Microgranite.

By C. Richardson and E. Caldwell, Newnham College, Cambridge.

DURING an expedition to the Lake District, led by Miss Elles, the contact of the Threlkeld microgranite with the rocks into which it has been intruded was examined. The lower contact of the microgranite with the Skiddaw Slates is now well exposed at the eastern end of the main quarry south of Threlkeld railway station ; and also in the light-railway cutting connecting this quarry with the newer quarries to the S.W. This contact is transgressive to the bedding of the slates, and at the first-named exposure the two rocks are dove-tailed into each other. The slate can be seen to be but slightly hardened and so little alteration has been effected that well-preserved graptolites were found within 18 inches of the contact.

The graptolites found were :—

Trigonograptus ensiformis (Hall).
Tetragraptus serra (Brong.).
Dichograptus octobrachiatus Hall.
Didymograptus extensus Hall.

So good is the preservation of these fossils that, as Miss Elles informs us, the *Trigonograptus* shows a reticulation of the test which seems to indicate that it should be classed with the Retiolitidae rather than with the Diplograptidae as has hitherto been done. Also this is believed to be the first record of *Trigonograptus ensiformis* in place in the Skiddaw Slates.

The contact was next seen in the light-railway cutting half a mile S.W. of the main quarry. It is well exposed on both sides of the track and, apart from a little hardening, there is no alteration of the slates. The microgranite has a narrow chilled border.

The upper contact of the microgranite was examined on Low Rigg, on the west side of St. John's Vale. The intruded rock lies against a set of coarse ashes of the Borrowdale Series among which is a fine, hard, dark green cleaved ash. No trace of Skiddaw Slate was found on this side of the microgranite, and it is possible that this fine ash was previously mistaken for highly metamorphosed Skiddaw Slate.

REVIEWS.

THE COUNTRY AROUND MORETON IN MARSH. By LINSDALL RICHARDSON, F.R.S.E., with contributions by A. E. TRUEMAN, D. M. WILLIAMS, R. C. GAUT, and H. G. DINES. Mem. Geol. Survey, Explanation of Sheet 217. 1929. 4*s*. 6*d*. net.

THE tradition of the Geological Survey district memoirs for putting forward the last word in detailed research is more than upheld by Mr. Richardson's latest contribution to their number. For the modest price of 4*s*. 6*d*. it is now possible to purchase a mass of valuable information far beyond the scope of the too-modest title. The author has made this memoir, in fact, nothing less than a complete compendium of the Jurassic geology of the main North Cotswold hill-mass, from Cheltenham and Bredon Hill in the west to beyond Bourton on the Water, Stow on the Wold, and Chipping Campden in the east.

The Lower Lias of the classic section at Battledown Brick Works, Cheltenham, provides the first demonstration of the changes in point of view brought about by the introduction of modern palaeontological methods—in this case following on the ammonite studies of Dr. A. E. Trueman. Dr. Trueman himself contributes an account, with Miss D. M. Williams, of the ammonite succession in the cuttings of the Cheltenham-Honeybourne Railway, in which some previous misconceptions are corrected. This and the accompanying tables of ammonite faunas render the memoir indispensable to anyone working on the Lias or on ammonite evolution.

It is the Inferior Oolite, however, which is the formation *par excellence* of the Cotswold Hills, and it is also the favoured child of Mr. Richardson's adoption. With admirable clarity and precision he describes the intricate series of deposits, which reach their maximum thickness in the synclinal of the Cleeve Hill plateau and feather out eastward against the anticlines of the Vales of Moreton and Bourton. The pioneer work of the late S. S. Buckman's early days is subjected to a severe test (for there can be few exposures of

Inferior Oolite between Northampton and Burton Bradstock that have escaped Mr. Richardson's scrutiny), and in general it emerges triumphant. Only a few minor matters have had to be corrected; the chief being the placing of the roofing slates of Hyatt's Pits, considered by Buckman to be Tilestones of the *concavi* zone, into the Chipping Norton Limestone Series, of *zigzag-fuscae* hemera. Another correction occurs in the *concavi* zone, a term Blockley Clay, of Mr. Richardson's own coining, proving to have been introduced on false premises. At the Holt Quarry, near Blockley, the clay underlies sand and sandy limestone formerly thought to be Harford Sands, but since proved to be a sandy facies of the Tilestones, and the clay below is therefore Snowshill Clay.

The spectacular over-riding of the Upper Inferior Oolite beds (*garantianae* and *truellei* zones) across the eroded edges of the underlying strata, as first worked out by Buckman, is brought out in an illuminating manner. The progressive overlap of these beds eastwards, until they come to rest on the Upper Lias, compares with the better-known overlap in the vicinity of the Mendip Hills, described by Mr. Richardson in a number of previous papers.

The chapters which contain, perhaps, the greatest amount of new information are the two dealing with the Chipping Norton Limestone, Fullers Earth, and Great Oolite. The tracing of these rocks westward from North Oxfordshire into the North Cotswolds was a work on which Mr. Richardson was first engaged many years ago, and it has now resulted in a novel appearance of the new edition of Sheet 217, where a new colour, bright green, has been introduced to mark extensive tracts of Chipping Norton Limestone about Condicote. Mr. Richardson considers the Chipping Norton Limestone a lateral replacement of the lower part of the Fullers Earth, and he groups it and everything up to and including the Stonesfield Slate in Marcou's Vesulian Stage. It should be remembered, however, that d'Orbigny included *Zigzagiceras zigzag* (which has been found at Chipping Norton) in his Bajocian Stage, and as the zone forms the upward continuation of the Inferior Oolite limestones both in Oxfordshire and in Dorset, where it constitutes the *Zigzag* Bed, it might be as well to drop the term Vesulian, which includes rocks of both Bajocian and Bathonian Stages (Fullonian Substage) and is therefore redundant. The linking up of this Cotswold Chipping Norton Limestone with the Hook Norton and Swerford Beds of Mr. Richardson's recent researches on the Oxon-Northants border, and so with the sandy beds of Newbottle Spinney and the White Sands of Southern Northamptonshire, is especially instructive.

Of great importance also is the recognition of a thin representative of the Upper Estuarine Clay as far west as the Condicote-Notgrove area, where it had previously escaped observation by being confused with the basal part of the Fullers Earth. It rests upon an eroded surface of the Chipping Norton Limestone, just as in Southern Northamptonshire it covers a deeply eroded surface of the White

Sands, and at one place, Bolton's Ground, near Condicote, it has at the base a greenish marl resembling the *Viviparus* Marl of Sharps Hill, Oxon, containing water-worn pebbles and corals.

The higher beds of the Great Oolite, of which a number of detailed sections are recorded, may be expected to fall readily into their place when Mr. Richardson has completed the memoir on the Cirencester district, with which he is at present occupied. This further extension of Mr. Richardson's survey will be eagerly awaited by those who value lucid descriptions of rocks and fossils that actually exist and can be seen, and who have turned with impatience from the theorizing and play with very long words that have encumbered much Jurassic literature in recent years.

Before the usual concluding sections on economic geology, a short chapter is devoted to Superficial Deposits, principally the work of Mr. H. G. Dines. The chief features of interest in this category are the so-called Cheltenham Sands, in the west, and the pre-glacial or Paxford gravel in the east. There are also boulder clays and river gravels, and it might perhaps be suggested that more could have been made of these if Mr. Dines had attempted to link up his work with the valuable results obtained by Dr. K. S. Sandford in the Upper Thames basin.

W. J. A.

Economic Geology. By H. Ries. 6th ed., pp. viii + 860, with 75 plates and 291 figures. New York: Wiley; London: Chapman & Hall, 1930. 30*s*.

THE present edition of this well-known work has been slightly increased in size and brought thoroughly up to date so far as statistical and other variable features are concerned, with references to recent work and discoveries. It is a valuable book of reference, especially so far as America is concerned.